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論 文 題 目	A Developmental and Autonomous Learning Framework for Integrated Active Depth Perception
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論文の内容の要旨

Developmental learning is essential for cognitive development. In this research, we examine one of its applications for robots which is active depth perception. Depth perception is one of the most fundamental problems for biological and artificial vision systems. Humans use several different cues to infer the depth layout of a scene or estimate the distance of individual objects. Usually, depth perception in humans is an active process involving different kinds of eye and/or body movements.

During active binocular vision, when an object is fixated with both eyes such that the optical axes of the two eyes intersect at a point on the object's surface, the vergence angle between the two eyes provides an estimate of the object's distance. When the observer moves sideways by a known distance, the eye rotations necessary to keep the object at the centers of gaze, the so-called motion parallax, also provide information about the object's distance. When the observer approaches the object with a known velocity, the changing optic flow pattern created by the movement also provides information about the object's distance. Note that while active depth perception based on vergence eye movements obviously requires at least two eyes, depth perception based on motion parallax or optic flow requires only a single eye. However, humans do not only use one active depth perception for their whole lifetime. They can utilize multiple active depth perceptions when they move. Thus, we consider the full active depth perception which are stimulated when the observer moves in a direction and looking at a specific visual field. All of the three-active depth perception are then evoked as (1) the eye rotation that is necessary to keep the previous visual field to compensate the lateral body movement. (2) the eye rotation required to reduce the disparity between two eyes.

The main goal of the research is to implement a biological inspired active depth perception framework for robots which is developmental and has the ability of self-calibration. A literature review of various studies implementing the vision system indicates that there are several ways to implement the active depth perception. One way is to use the conventional computer techniques to create the depth perception algorithm. Despite their

impressive accuracy of the depth perception, most of the frameworks fails to adapt and learn to various environment. So, to solve the problem, some studies proposed the framework with learning algorithms which generally solve the learning issue. However, the studies fail to create a link between action and perception which is important for creating a developmental learning framework.

In this thesis, we describe the works that relate to the research and how we solve the problem with the proposed frameworks such as generating smooth pursuit eye movement when the robot moves in a lateral direction, estimating the distance between the robot and the fixating object with motion parallax, extending the presented visual learning framework to accurately and autonomously represent the various ranges of absolute distance by using the pursuit eye movements from multiple lateral body movements, integrating motion parallax and stereo vision cue within one framework.

Finally, we show that the proposed models, which are implemented in the HOAP3 humanoid robot simulator, can successfully solve the problem that is raised toward achieving the main goal.

Keywords: Active Depth Perception, Cognitive Developmental Robot, Autonomous Learning, Motion Parallax, Self-Calibration, Active Efficient Coding, Integrated Cue, Distance Estimation, Developmental Vision, Eye pursuit, Sensory-motor Coordination

論文審査の結果の要旨

This dissertation addresses the problem of brain-inspired visual learning framework that endows autonomous robots with human-like capabilities of integrating multiple visual cues for active depth perception. The author's main contribution is two-fold: First, he proposed a developmental learning framework that can adapt to various environments linking body movement and visual perception; second, he implemented the integration of motion parallax and stereo vision cues within a single framework, paving the way toward a better understanding of human cognitive information processing. The effectiveness of the proposed approach was verified through extensive numerical simulations and experimental validation with a real system. Overall, this research opens doors to impactful change in the perceptual information processing architecture for autonomous robots.

Specifically, the author proposed a visual learning framework to accurately and autonomously represent the various ranges of absolute distance using smooth pursuit eye movements from multiple lateral body movements. The proposed self-trainable depth perception model has been published in the Elsevier's Robotics and Autonomous Systems Journal, one of the prestigious journals in the field of robotics. In contrast to most of existing depth perception approaches that rely on stereo parameters and manual calibration, this work is considered the very first attempt to learning sensorimotor mapping from experience, without any *a priori* information. Furthermore, the author proposed a method that selects the amount of necessary lateral movement to achieve the target depth distinguishability with the minimal time of movement. This allows robots to learn their optimal movement to distinguish between the perceived distance of two objects, which is one of the most important decisions for autonomous mobile robot navigation. The proposed framework can be used in a wide variety of real-world applications utilizing the interaction of robot action and perception.

This is an excellent dissertation and we approve awarding a doctoral degree to PRUCKSAKORN, Tanapol.