Japan Academy Prize to:

Yoshihiko Nakamura
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for "Fundamental Research on Computation and Control of Humanoid Robot Motions"

Outline of the work:

An object in the physical three-dimensional world has a six-degrees-of-freedom state represented by six variables: three for position and three for orientation. An industrial robot, which performs to pick and place parts in factories, is designed to generate motions of six degrees of freedom as they are necessary and sufficient for its task. Recently, however, robots from which more general and dexterous motions are expected, are designed to have many more and redundant degrees of freedom. Humanoids are the most representative ones, and require coordinating more than 40 degrees of freedom for its purpose. Dr. Yoshihiko Nakamura has developed a fundamental and theoretical foundation for computation and control of such high-degrees-of-freedom humanoid robot systems, and has expanded its use for human biomechanics applications.

Development of fundamental theories and methods of computation for motion control of multi-degrees of freedom systems

In humanoids, the freedoms of legs are mainly used for walking and maintaining stability, but also are related to the generation of hand motion. Reversely, the freedoms of hands are mainly used for producing hand motion, but also play a role for the stability of walking by coordinating their movements with the waist. These intermixing roles change depending on the purpose of motions and the environment in parallel and simultaneously. In humanoid control, the desired motion needs to be eventually attributed to the motions of each degree.

The basis of that assignment strategy is the concept of Redundancy Control by Task Priority, proposed and developed by Dr. Nakamura. The redundancy control problem appears not only in how the degrees of freedom are distributed, but also in how forces are distributed for a given task. Example cases are that of when holding an object with multiple fingers, or when leaning against a wall with a hand while standing with both feet. Dr. Nakamura formulated these redundancy control problems as large-scale optimization with constraints that arbitrate many requirements and limitations of robot capabilities. This optimization problem must be solved several hundred to thousand times a second. Dr. Nakamura devised efficient computational algorithms, especially for forward dynamics (compute expected motion when motors exert certain forces) that demand a higher computational load, as well as for backward dynamics (compute forces that motors must exert for generating desired motions). They enabled precise and real-time control of the reaction forces from the floor, and the force between hands and environments.

Biomechanics model of human motion

Dr. Nakamura applied his efficient dynamic computation method to a biomechanics model of a human: a system with further more degrees of freedom. He developed a whole-body model by attaching mass to individual parts of the body skeleton and approximating the individual muscle by a tension wire. The system was commercialized and used to estimate the dynamics of whole-body muscle tensions during sports action by an Olympic athlete, as well as during rehabilitation exercises of people.

Finally, inspired by the mirror neurons of brain science, Dr. Nakamura studied the bidirectional computation relationships of perception and movement by a human. It led to creating a symbol system to describe human motions, and then connecting it with natural language for human-robot communication. This can be regarded as a forerunner in research for today's robot embodiment by generative AI with a large language model.

List of Main Publications

(1) Y. Nakamura, H. Hanafusa and T. Yoshikawa, "Task Priority Based Redundancy Control of Robot Manipulators," International Journal of Robotics Research, Vol. 6, No. 2, pp. 3–15, 1987.

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(15) T. Ko, K. Yamamoto, K. Murotani and Y. Nakamura, "Compliant Biped Locomotion of Hydra, an Electro-Hydrostatically Driven Humanoid," Proceedings of IEEE-RAS International Conference on Humanoid Robots (Beijing, China, November 6–9, 2018). IEEE, pp. 587–592, 2018.

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