Creative Research Initiative Program

Digital Nanolocomotion Center

Research Theme	Realization of Bio-inspired Digital Nanolocomotion
Keywords	MEMS/NEMS, Digital Muscle Chip, Bio-analogy, Nanolocomotive Engine, Digital Nanoactuation, Micromechanical Nanomodulation, Nanotechnology
Major Activities	Research and Development Education and Training International Exchange and Collaboration
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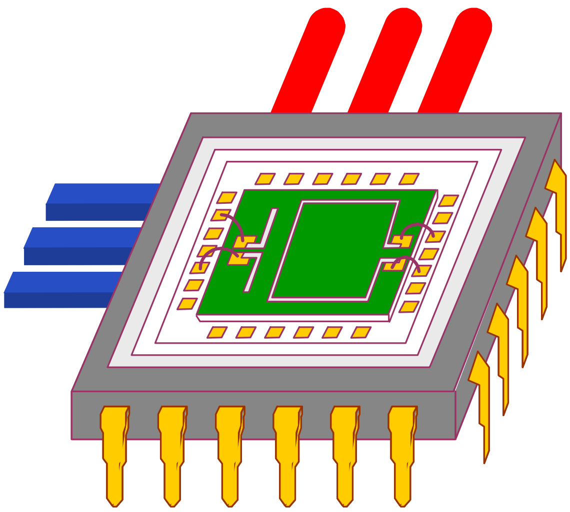
Integrated Digital Muscle Chip



Integrated digital nanolocomotion systems for the high-precision control and the cost-effective manipulation of nano/micro information carriers: mechanical, thermofluidic, optoradiative, and biochemical signals or substances.

Research Plan

1. Problem Definition or Motives

Recently high-tech products, such as information, communication, biomedical and environmental devices and systems, have been miniatured not only for the enhancement of speed and function, but also for the reduction of energy and resource consumption. Advanced high-tech products require locomotive function for the precision control and effective manipulation of a wide variety of information carriers in the form of optical, chemical and biological microenergy or substances. Successful development of miniatured locomotive devices, however, has been constrained by the limited understanding of physical phenomena as well as by the lack of the scientific knowledge and engineering data on the material behavior and properties in both nanometer and micrometer regimes.

In the living creatures, however, we can find very effective locomotive engines in nanometer regime that enables the mobile creatures to be more active and productive than the immovable ones. In this research, we propose to analyze the locomotion of living creatures, to understand the fundamental principle and the associated physical phenomena arising in the nanometer cells, to develop augmented locomotion principles suitable for micrometer scale components through the physical analogy and proper modification of energy transduction methods; thereby eventually creating a new class of nanolocomotive engine suitable for the fine manipulation of optical, chemical and biological information carriers.

The research on the nanolocomotive engine requires creative and intensive investigation on the physical phenomena in the microregime (Table 1). Since the microregime is the fused area of science and engineering, we would like organize a transdisciplinary research center, where both the scientists in physics, biology and chemistry and the engineers in mechanics, electronics and materials, develop cooperative research activities across the disciplines. Such transdisciplinary research is expected to produce a strong technological impact on the science and engineering in the microregime, whose effect may propagate to a wide spectrum of technological space; thereby creating a prime technology basis for the advanced miniatured products in the 21st century.

Table 1. Research theme and characteristics

Research theme	Element size	Key materials	Technology regime
macro-locomotion	cm ~ mm	metal (bulk)	engineering (macro-regime)
bio-analogic nano-locomotion	**mm ~ μm**	**inorganic & metals (film)**	**fused regime of science and engineering (micro-regime)**
bio-locomotion	μm ~ nm	organic	science (nano-regime)

2. Research Hypothesis or Key Ideas

There have been two different approaches in the microdevice research and development: 1) mimetic size reduction of the existing macro-scale devices; 2) mimetic size enlargement of the native creatures. The mimetic scale-up and scale-down approaches may not effective for our nanolocomotion research. Instead of taking the simple mimetic approaches, we propose a bio-analogic scale-up approach where the physical analogy of the bio-actuation principle (Fig.1) is performed to find the proper actuation principles for the MEMS-based nanolocomotive engines. The nanolocomotive engine, composed of digital microactuators and micromechanical modulators, is designed to perform the micromechanical modulation of the digital microactuation in order to achieve the nano-precision locomotion within the micrometer-range.

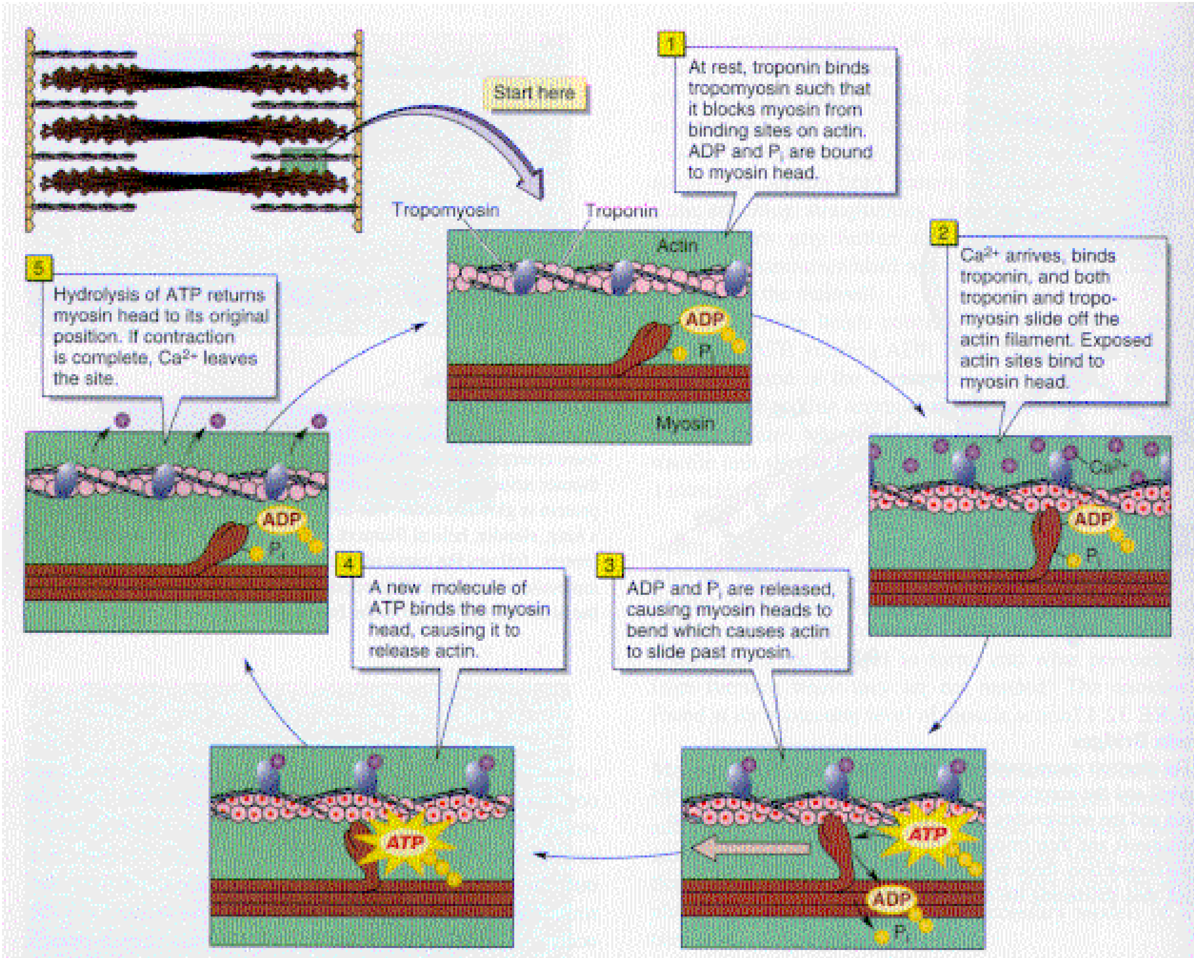


Fig.1 Muscle actuation principle and mechanism.

In the microregime, the dominance and mechanism of the physical effects may differ from those in macro and nano regime: for example, the viscous force, electrostatic force and surface tension in the microregime tend to be more dominant terms than the inertial, elastic and friction forces in the microregime. Using the past 14-year research experience in the microregime, we are going to focus on the phenomena and principles in the nanoregime, whose examples are found in the living creatures. On the basis of the identification and understanding of locomotion principles and the associated phenomena in nano(bio)regime, we intend to create or invent proper locomotion principles and methods to be used in microregime through the analogy and augmentation of energy transduction principles and transport mechanisms involved. The new principles and methods will be verified by the experimental study using the test (proof-of-principle) vehicle fabricated by micromachining technology. The proven nanolocomotion technology will provide a missing link between science and technology, as well as new technological tools for future industry.

3. Research Contents and Structure

3.1 Goals

We define a figure-of-merit (FOM) of the nanolocomotive engine, as shown below.

$$FOM \equiv \frac{Enviroment \times Function}{Cost} \times \frac{Load\,(Force) \times Velocity}{Energy\ consumption} \times \frac{Range}{Precision}$$

Using the MEMS technology, we miniaturize the locomotive engine to reduce the “Cost” required for high-quality “Environment.” We can also increase the number of “Function” per unit “Cost” through the MEMS component integration. Thus, we are going to maximize the “Range-to-Resolution ratio” of the nanolocomotive engine, while satisfying the required performance output, “Load×Velocity,” and the minimum input “Energy Consumption.”

Therefore, the ultimate goal of this research is to exploit new principles and methods of bio-analogic nanolocomotion that can accomplish the nanometer precision with the “Range-to-Precision ratio” of 1,000-100,000, while satisfying the required output “Load×Velocity” characteristics at the minimum “Energy Consumption” conditions. We also verify the feasibility of the principles and methods by the experimental characterization of the fabricated nanoactuators.

Thus, the most challenging issue in this research is to find the principles and methods to overcome the technological difficulties placed by the conventional microactuator technology, including the problems generated by electrical noise, micromachining tolerance and materials property uncertainty. In this research, we attempt to solve these problems using the creative analogy of the biological locomotion, thereby achieving a break-through in the advanced actuator technology for future.

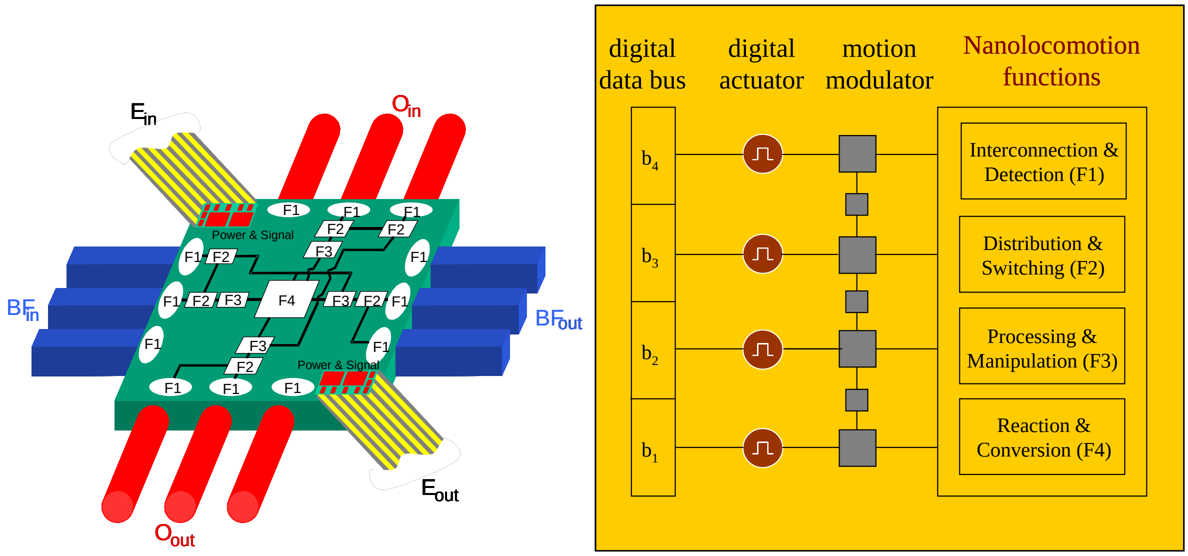
3.2 Research theme and regime

We first investigate the locomotion created by the cell in biological (or nano) regime, but we eventually intend to develop or create the locomotion generated by the microdevices in micro regime through the proper analogy of the biological principles and phenomena into those in the microregime. Thus, we will focus on the physical phenomena (Table 1) in the micrometer to millimeter range, whose technological aspect can be differentiated not only from that in millimeter scale, but also from that in nanometer scale.

3.3 Research model

We define the digital nanolocomotion engine (Fig.2a) as a nano-precision microactuator system, in which the microactuator modules (Fig.3), composed of digital microactuators and motion modulators in the size of mm~μm, are combined together to achieve the nanometer precision locomotion required for high-precision control and cost-effective manipulation of the non-electrical information carriers, such as optical, biochemical, thermofluidic microenergy or substances.

The major functions (Fig.2b) of the nanolocomotion engine include the interconnection & detection, the distribution & switching, the processing & manipulation and the reaction and conversion of optical, biochemical, thermofluidic information carriers using the electrical signals. For each functional component, we focus on the locomotive devices (actuators and modulators) required for the high-precision control and the cost-effective manipulation of microenergy or substances. We intend to realize the nano-precision locomotion by finding the most effective paths in the energy transduction network (Fig.3) connecting mechanical, electrical, thermofluidic, optoradiative and biochemical realms.



(a) Physical model in the form of digital muscle chip. (b) Functional decomposition of components.

Fig.2 Concept of digital nanolocomotive engine.

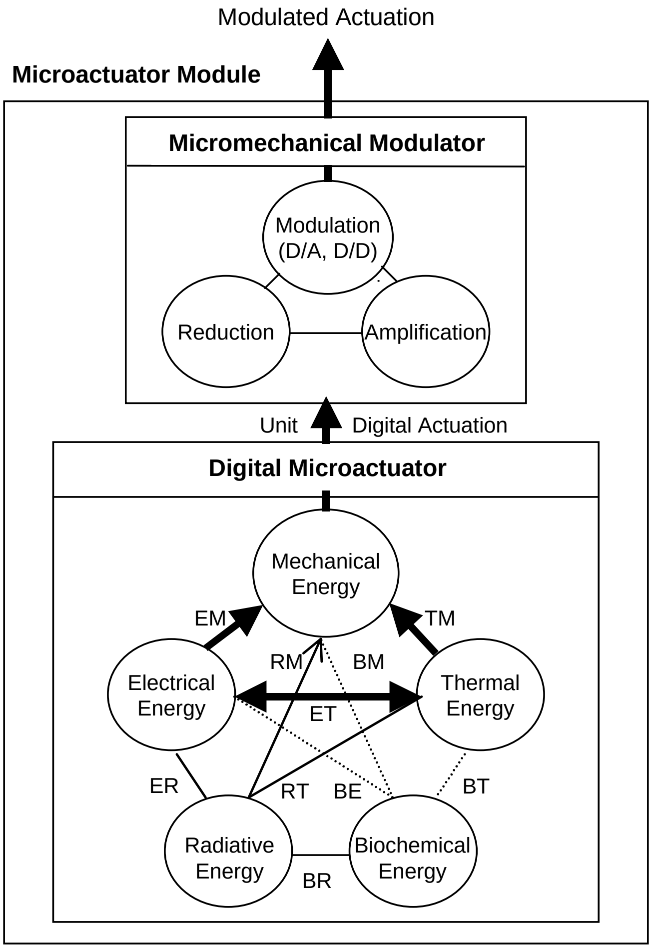


Fig.3 Eenergy transduction and manipulation for nanolocomotion.

3.4 Research scope, contents and plan

Table 2 and 3 show the fundamental actuation types and the associated principles considered in this research. Table 4 indicates the scope and the contents of the research.

Table 2. Actuation principles, methods and applications.

Principle	Method	Application
electrical	electrostatic, electromagnetic, piezoelectric	sliding, gliding, stepping, jumping (bouncing) actuation
thermofluidic	thermal, pneumatic, hydraulic, thermopneumatic	expansion (compression, circulating), propulsion (explosion, injection)
radiative	optical, radiative, electromagnetic wave	wireless (remote) actuation, induced (indirect) actuation

Table 3. Locomotion types, bio-examples and characteristics

Locomotion type	Bio-example	Characteristics			
		Range	Precision	Time const.	Force
sliding/gliding	muscle	nm - μm	high	μsec-msec	small
stepping/jumping	ants/flea	μm - mm	moderate	msec-sec	moderate
expansion/propulsion	mosquito/cutter fish	μm - mm	low	μsec-sec	large

Table 4. Research contents and plans

Phase	Research Contents
Phase One (3 years)	- Engineering models of bioactuators and biomodulators - Experimental data on physical phenomena and material properties in nano- and micro-regimes. - Engineering models of digital microactuators and micromechanical modulators. - Design, fabrication and test results of digital microactuators and micromechanical modulators.
Phase Two (3 years)	- Design, fabrication and test results of digital nanoactuation modules based on the electromagnetic and thermofluidic principles. - Research results on indirect/remote microactuation
Phase Three (3 years)	- Assembly of digital nanoactuation modules - Design, fabrication and test results of digital nanolocomotion - Characterization and application of the bio-analogic nanolocomotion

3.5 Subgroup Organization & Strategy

1) The research group consists of two subgroups as listed in Fig.3 and Table 5.
2) Each subgroup consists of 1 leader and 8~10 researchers, including post-doctoral researchers.
3) Experimental verification of the theoretical principles and methods is mandatory.
4) Transdisciplinary research and interaction is mandatory.
5) Evaluation and Advisory Board consists of people from industry and government.
6) Feedback from regular research presentations to academia, industry and government.
7) Collection and public distribution of technological information through the internet.
8) Development of specialized education and training programs in MEMS area.

Table 5. Research group and technology focus

Subgroup		Subgroup I	Subgroup II
Focused technology (Key research areas)		digital actuation (electromechanical and thermofluidic actuators)	micromechanical modulation (flexural and thermofluidic modulators)
Energy path of Fig.3	major	EM, TM, CM & ET, EC, TC	MM, MMM
	minor	MM	EM, TM, CM

4. Center Activities and Managing Strategy

Activities	Directions	Goals	Key factors
Research and development	- Future core technology - Experimental verification of fundamental principles and the associated physical phenomena - Creative fusion of emerging technologies	Creative, future and core technology	Originality Usefulness Next-generation Technical impact
Education and training	- Transdisciplinary research promotion - Creative research leader education and training - Multidisciplinary technology specialty - Practical hand-on experience	Transdisciplinary, comprehensive and experienced research leader	Expertise Enthusiasm Curiosity Comprehensiveness
Facility and process	- Outsourcing the standard process - Focusing on new and nonstandard process - Diverse materials and processes	MEMS-oriented process and materials	Flexibility Safety
Network and collaboration	- Technology alliance - Fundamental data acquisition - Technology application and transfer - Network on technology, information, facility and researchers	Interactive, pleasant and effective network	Complimentary Cooperative Mutual benefit

5. Potential Value of Research Theme

5.1 Scientific and Technological Values

1) Identification and understanding of biological locomotion principles.
2) Understanding and application of nano & micro physical phenomena.
3) Establishment of database for nano & micro material properties and behavior.
4) Exploitation of new technology in the fused area of science and engineering.
5) Finding of missing links between nanoscience and microengineering.
6) Expansion of the technological space of nanoscience and microengineering.
7) Technology breakthrough in long-range and high-precision actuation.

5.2 Socio-Economic Values

1) Development of new high-tech products based on the locomotion in nano & micro regimes.
2) New tools for the effective control and manipulation of optical, chemical and biological information.
3) Production of miniatured, high-speed, low-power, low-cost microdevices and products.
4) Enhancement of the detection, storage, display, printing functions activated by locomotion.
5) Opportunity of new business and/or market creation based on nano & micro technology.
6) Production of patents, research papers and intellectual properties.
7) Training of researcher leaders armed with an intellectual creativity in emerging technology areas.

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