RESEARCH IN MICRO-NANO-ROBOTICS

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Abstract: Research in Micro-Nano-Robotics comprises a very broad field and an advanced scientific field highlighting thus the "robotic / micro-nano-robotic science and engineering ", which has developed and develops technical, technological, measurement / control, inspection micro-nano-robots, robots fulfilling functions vital to human beings, robots delivering ultra-precise medical services, etc. This research, applied in all these areas and other areas still not mentioned, now passes to a higher development phase, in accordance with the development of electronics / microelectronics, mechatronics / micro-nano-mechatronics and computer science / micro-nano computer science, called Micro-Nano-Robotics. Micro-Nano-Robotics, in its evolution, especially in its future evolution, develops in accordance with the development of micro-nanotechnologies and micro-nano-materials, predicting for the future, a „Micro-Nano-Robotics at human anatomy level” and generating for the future "a population and a humanoid new society ". So, we need to define Robotics in general and especially Micro-Nano-Robotics.

Keywords: robotics, micro-robotics and nano-robotics, micro-nano-manipulation

1. Robotics - Robots

The definition of robotics is done worldwide in several institutions, either international standardization institutions (such as the International Organization of Standardization - ISO, Verein Deutscher Ingenieure - VDI, Germany, or Japanese Industrial Standards - JIS), international institutions for scientific research (such as the Robot Institute of America - RIA) or technological institutions or organizations (such as Robot Technology of Japan).

According to ISO, the definition of the (industrial) robot is: "the (Industrial) Robot is the mechanical manipulator with programmable movements, multifunctional, with some degrees of mobility and able to perform material handling operations of parts, tools or special technological devices through variable programming of movements, for achieving a variety of functions."

According to JIS, the definition of the (industrial) robot is: "the (Industrial) Robot is the mechanical system with flexible movements similar to the functions specific to living organisms or that combines these features with specific functions specific to intelligence and that acts in response to human commands ".

According to VDI, the definition of the (industrial) robot is: "the (Industrial) Robots are universal automates with linear or angular movements after several directions, and then can be programmed as needed (without mechanical intervention in the system), and in some cases performing movements basing on commands from sensors; are endowed with grippers, tools or other manipulation devices for the execution of works or operations in technological processes. Whatever the definition, a complex (industrial) robot comprises the sensory systems, through which, a partial or total environmental adaptability is allowed. Besides this, the presence of sensory systems, especially the complexity degree and the generation of sensory systems and respectively of sensors / micro-sensors, results in a history of generations of sensors, leading now to the fourth generation and the fifth generation including an evolution of mechanical and mechatronic systems, of auctioning and micro-auctioning systems, of data acquisition and information processing systems, of automatic image processing systems and artificial intelligence systems.

The evolution of generations of industrial robots, unlike the evolution of information technology involves a permanent extension and expansion of applications and therefore a permanent expansion of the areas of implementation, the development and modernization of all the efficient subassembly components, and coexisting with those of previous generations.

A brief and synthetic characterization of the generations of industrial robots includes:

- (industrial) robots from the first generation, type programmable automates, which require a stable,
determined environment and a work program with a prescribes a sequence of operations, industrial robots feature internal sensors / micro-sensors for the determination of displacements in different positions or kinematic chain couplings; also these industrial robots can be programmed "to learn" and after storing successive actions, they may be used once or several times, depending on what is required; this type of industrial robots, and robots can type "point by point", which may serve to building parts, tools or other different machines or manufacturing cells / systems that can carry out various technological operations, etc.;

- (industrial) robots from the second generation are modular and feature opportunities for integrating multiple sensory systems, from simple sensory systems to complex sensory systems, and able to detect, transfer and process environmental and process information providing partial or total adaptation to the environment and to the process; in this generation, the robots find their application in technological processes, for service for parts, tools and technological devices moved, for example, on imposed trajectories;

- (industrial) robots from the third generation are equipped with artificial intelligence systems capable of the following: geometric shape recognition of landmarks, natural language acquisition, assimilation of self-learning process, etc., with a sensory system not lacking investigation sensors / micro-sensors, tactile sensors / micro-sensors, etc. and a high degree of adaptability that allows decision-making and development of work programs in accordance with the working environment, these robots having different types of reactions:
  o reflex reactions;
  o behavioural reactions;
  o reasoning reactions.

- (industrial) robots from the fourth generation are equipped with advanced neural micro-informatic equipments capable of decisions-making based on possible problems arising unforesen and able to change the program in light of the undesirable characteristics encountered and capable of actions close to human actions; these industrial robots are able to work "in tandem", supplementing if necessary, by generating, important functions critical to achieving "the completing logic";

- (industrial) robots from the fifth generation, are equipped with nanoscale micromechanical structures with advanced sensory neural systems, latest generation processor systems and ultra-intelligent software capable of continuous self-learning and self-adaptable for other new activities generated by "personal decisions"; these robots are on the same level with "the human beings in all its functions and characteristics;

- (industrial) robots from the fifth generation the sixth generation, are endowed with nanometric and subnanometric integronic structures with very advanced integronic sensors, with integronic processor generation systems with high and super sophisticated software capable of generating human behaviour and behaviour similar to human behaviour and even higher behaviour in certain functions.

2. Micro-robotics and nano-robotics

Micro-robots are complex micro-systems which feature a microstructure consisting of micro-actuators with hardware, micro-sensors, electronic micro-informatic micro-units, intelligent software for intelligent signal processing and information processing in general. Micro-robots applications are different from those of robots, and are different from the manufacture of micro-robots. The activity of research - innovation in the world of micro-robots is different from that in the world of robots, and the same is true of programming - as well as the ability for algorithm building and micro-manipulation and behaviour in risk environments.

So, the world of micro-robotics does not continue, as the world of robotics components, but builds, specifically, the world of micro-actuators, of intelligent electronic micro-sensors and micro-units and micro-informatics. In this context, it is necessary to study individually and to perform a compared study of each and every micro-component and micro-element, regardless of their stage, at a time, in a new conception of approach and evaluation, of real and virtual knowledge.

3. Micro-Nano-Manipulation

Micro-nano-manipulation or control of the position and / or force at micro-nano scale is a key enabling the micro-nano-technology of filling the gap between "tip-base" strategies and "base-tip" strategies and that can lead to the emergence of replicating micro-based molecular nano-ensembles. These types of micro-nano-assembled devices have been proposed as general manufacturing devices with a wide range of useful micro-nano-products and their replicas (self-replication).

Currently, micro-nano-manipulation can be applied to the scientific exploration of physical and biological mesoscopic phenomena and prototype micro-nano-devices. It is a fundamental technology for characterizing the properties of nano-materials, nano-structures and nano-mechanisms, preparation and assembly of micro-nano-groups and micro-nano-devices for nano-electro-mechanic systems (NEMS).

Micro-nano-manipulation was made possible by the invention of STM, atomic force microscopes (AFM) and other types of microscopes for scanning the sample (SPM). In addition, optical tweezers (laser tube) and magnetic tweezers are also possible micro-nano-manipulators. Micro-nano-robotic manipulators (NMRs) are characterized by 3D positioning capability, control orientation, the effect of multiple independent and real time self-observation systems that can be integrated with sample scanning microscopes. NMRs greatly
expand the complexity of nano manipulation. A brief comparison of the STM, AFM and NMR technologies is shown in Figure 1. With comparable image resolutions, a STM can be applied in particles as little as atom resolution atoms. However, limited by its 2D positioning and the manipulation strategies available, standard STMs are not good for complex manipulations and cannot be used in 3D.

In general, micro-nano-manipulation with AFM involves moving an object by touching it with a pinch. A typical manipulation is as follows: first image of a particle in non-contact mode, removing the tip oscillation and the tip scanning over the particle in contact with the surface and the weak response. The mechanical movement can exert strong forces on objects and thus can be applied to handle larger objects. 1D and 3D objects can be manipulated on a 2D substrate.

However, micro-nano-manipulation of individual atoms with AFM remains a challenge. By separating the functions of image spheres realization and manipulation, nano-robotic micro-manipulators can have more degrees of freedom including rotation for orientation control and thus it can be used to manipulate 0D objects (symmetric) to 3D objects in 3D space. Limited by low resolution electron microscopes, NRMs are difficult to use for manipulating atoms. However, general robotic capabilities including 3D position, orientation control, multiple effectors acting independently, separated real-time observation system and the integration with SPMs is promising for complex NRMs micro-nano-manipulation.

The first micro-nano-manipulation experiment was conducted in 1990, using a STM and materials at low temperatures (4 K) to position individual xenon atoms on a single crystal nickel surface, with atomic precision. The manipulation allowed the manufacturing of rudimentary structures atom by atom.

A micro-nano-manipulation micro-nano-system generally include micro-nano-robotic positioning devices such as microscopes as "eyes", various effectors including samples and tweezers among others as "fingers", types of sensors (force, displacement, tactile, power, etc.) to facilitate handling and / or to determine the properties of objects. Key technologies for micro-nano-manipulation include observation, actuation (excitation), measurement, design and manufacturing, calibration and control, communication and human-machine interface systems.

Nano-manipulation strategies are determined by the environment - water, liquid or vacuum, which is decided upon depending on the properties and size of objects and methods of observation. Figure 4 represents nano-manipulation microscopes, micro-environments and strategies. To see the handled objects, a STM can provide sub-Angstrom resolution image, while an AFM is capable of providing atomic resolution. Both can achieve 3D surface topology. Since an AFM can be used in the surrounding environment, it provides a powerful tool for bio-manipulation which may require a liquid medium.

The resolution of electronic microscopes for scanning (SEM) is limited to about 1 nm, while SEM field emission sites (FESEM) can provide higher resolution. SEMS / FESEM can be used for researching both real-time 2D objects and for the effectors of manipulators and in large, ultra high vacuum rooms (UHV) offering enough space to include a NRM with many degrees of freedom (DOFs) for 3D nano-manipulation.

However, the 2D nature of research makes difficult the positioning along the electron beam direction. Electron microscopes with high resolution transmission (HRTEM) can provide atomic resolution. However, narrow room type UHV makes it difficult to incorporate large manipulators. In principle, optical microscopes (OMs) cannot be used to observe micro-nanometre scale areas (smaller than the wavelength of visible light) due to diffraction limits. Near field scanning optical microscopes (SNOMs) break this limitation and are promising for real-time observation devices for micro-nano-manipulation, especially for the surrounding environment. SNOMs can be combined with AFMs and NRMs for micro-nano-scale bio-manipulation.
Micro-nano-manipulation processes fall generally into three categories: (1) lateral non-contact (2) lateral contact and (3) vertical manipulation. In general, lateral non-contact micro-nano-manipulation is applied to atoms and molecules in UHV with a STM or bio-object in liquid using optical or magnetic tweezers. Contact micro-nano-manipulation can be used in almost any environment, generally with an AFM, but it makes it difficult to manipulate atoms. Vertical manipulation can be performed with NRM. Figure 3 shows the basic processes of these three strategies.

In the figure, A, B, C, ... are positions of effectors (tip), A, B, C, ... positions of objects, 1, 2, 3, ... final effectors movements 1, 2, 3, ... movements of objects. Tweezers can be used to facilitate the collection, but generally not useful for the arrangement. (A) Lateral micro-nano-manipulation (adjustable), (b) Lateral contact micro-nano-manipulation (pushing), (c) Vertical micro-nano-manipulation (collection and settlement).

The movement of the processes of non-contact lateral manipulation is shown in Figure 3 a. The applicable effects able to cause motion includes attractive Van der Waals forces (VdW), generated near the tip of the sample, induced electric fields caused by the potential difference between the tip and sample, local heating or vibration by inelastic tunnelling current. With these methods some micro-nano-devices and molecules have been assembled. Optical and magnetic tweezers are likely to use non-contact manipulations of micro-nano order of DNA bio-probes. The lateral non-contact combinations with STM revealed several possible strategies for manipulating atoms and molecules. Pushing or pulling objects on a micro-nanoscale surface with an AFM is a typical manipulation using this method, as shown in Fig. 3 b. The first experiments have shown the effectiveness of this method for manipulating nano-particles. This method was also present in micro-nano-building and bio-manipulation. A virtual-reality interface facilitates such a manipulation and may create an opportunity for other types of manipulations. This technique was used in manipulating nanotubes on a surface.

The task of gathering and placing as shown in Fig. 5 c is significant for 3D micro-nano-manipulation, since its main purpose is to assemble prefabricated groups in devices. The main difficulty is to achieve enough control of the interaction between the object and the object and between the object and the substrate. Two strategies were investigated for micro-manipulation and proved to be useful for micro-nano-manipulation. A strategy is to apply a dielectrophoretic force between a tool and an object as an additional external force controllable by applying a polarization between the tool and the substrate on which the object is placed. Another strategy is to modify the Van der Waals forces and other intra-molecular forces between the object and substrate.

4. Micro-nano-robotic micro-nano-manipulation micro-nano-systems

Micro-nano-robotic micro-nano-manipulators are basic components of micro-nano-robotic micro-nano-manipulation micro-nano-systems. The basic requirements for a system of micro-nano-robotic micro-nano-manipulation include the resolution for micro-nano scale positioning of a workspace large enough, with enough degrees of freedom and including those for the rotation for 3D positioning and control of the orientation of effectors and generally multiple effectors for complex operations.

A micro-nano-manipulator available for purchase installed inside a SEM is shown in Figure 6. The micro-nano-manipulator has 3 degrees of freedom and a resolution from sub-nanometre to micro-nano-meter scale (Table 1).
The progress of micro-manipulation is many possible applications for micro-nano-manipulators and insert more (DOFs) within the vacuum chamber of a microscope.

To build micro-nanostructures based on multi-layer carbon nanotubes (MWCNTs) micro-nano-manipulators position and orient nanotubes to manufacture samples and nanotube transmitters, to achieve micro-nanowelding with deposit induced by electron beam (EBID), to characterize the single nanotubes in order to select and to characterize the strength of junctions at the test connection.

Research shows that when moving / scanning in the direction of A / B by the q1 / q2 fitting, the additional linear motion in C is very small. For example, the arm length is 50 nm, the additional movement in the direction of C is only 0.25-1 nm when moving in the direction A for 5-10 mm, and these errors can be ignored or compensated with an additional movement of prismatic coupling p3, which has a resolution of 0.25 nm.

Figure 5 a shows a micro-manipulation system nano-robotic which has 16 degrees of freedom (DOFs) in total and can be equipped with three or four peaks AFM to study the effect of both micro-nano-manipulation and measurement. Table 1 presents the system specifications.

Table 1 shows the functions of the micro-nano-robotic systems for nano-robotic micro-nano-manipulation for micro-nano-instruments, micro-nano-assembly and micro-nano-fabrication. The positioning resolution is of sub-nanometre scale and the movements are expressed in centimetres. Micro-nano-systems are not only for micro-nano-manipulation, but also for micro-nano-assembly, micro-nano-fabrication and micro-nano-instruments. Measurements of semiconductor samples are probably the most complex micro-nano-manipulations that this micro-nano-system can do, because it is necessary to stimulate independent samples by several micro-nano-manipulators. Theoretically, 24 degrees of freedom (DOFs) are required for (four) general purpose micro-nano-manipulators that is 6 (DOFs) for each micro-nano-manipulator for complete control of three linear (DOFs) and three rotation (DOFs). However, 16 (DOFs) are enough for this specific purpose. In general, two micro-nano-manipulators are enough for most tasks. More samples ensure more applications.

For example, three micro-nano-manipulators can be used for micro-nano-tube assembly of a transistor, a third sample being applied to cutting a tube placed in two other samples, four samples can be used for four-terminal measurements to characterize the electrical properties of a nanotube or a nanotube junction. There are many possible applications for micro-nano-manipulators if all the (four) samples are used together. The progress of micro-nanotechnology, can limit the size of micro-nano-manipulators and insert more (DOFs) within the vacuum chamber of a microscope.

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<table>
<thead>
<tr>
<th>Element</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Operating range: q1 and q2</td>
<td>240°</td>
</tr>
<tr>
<td>Operating range: Z</td>
<td>12 mm</td>
</tr>
<tr>
<td>Resolution (horiz.)</td>
<td>10^{-2} rad (5 nm)</td>
</tr>
<tr>
<td>Resolution B (vert.)</td>
<td>10^{-2} rad (3.5 nm)</td>
</tr>
<tr>
<td>Resolution C (linear)</td>
<td>0.25 nm</td>
</tr>
<tr>
<td>A fine range (scanning)</td>
<td>20 μm</td>
</tr>
<tr>
<td>B fine range (scanning)</td>
<td>15 mm</td>
</tr>
<tr>
<td>C fine range (scanning)</td>
<td>1 mm</td>
</tr>
<tr>
<td>Speed A, B</td>
<td>10 mm / s</td>
</tr>
<tr>
<td>Speed C</td>
<td>2 mm / s</td>
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</table>

Fig. 5 a, b. Nano-robotic system. (A) Nano-robotic manipulators, (b) Components of the system

A micro-nano-laboratory is shown in Figure 5 b and its specifications are in Table 2. The Micro-nano-laboratory integrates a micro-micro-robotic micro-nano-manipulation micro-nano-system with an analytical nano-system and a nano-nano-fabrication system and can be applied to the micro-nano-manipulation of nanomaterials, nano-manufacturing groups, micro-nano-assembly of nano-devices and in situ analysis of properties of such materials, groups and devices. Micro-nano-robotic nano-manipulation in a nano-laboratory has opened a new way for building nano-systems in the 3D space and to create opportunities for new processes and nano-fabrication of nano-instruments.
Table 2

<table>
<thead>
<tr>
<th>Element</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Micro-nano-robotic manipulation system</td>
<td></td>
</tr>
<tr>
<td>DOFs</td>
<td>Total: 16 DOFs</td>
</tr>
<tr>
<td></td>
<td>Unit 1: 3 DOFs (x, y and β, gross)</td>
</tr>
<tr>
<td></td>
<td>Unit 2: 1 DOF (z, gross), 3-DOF (x, y, and z, pure)</td>
</tr>
<tr>
<td></td>
<td>Unit 3: 6 DOFs (x, y, z, α, β, γ, ultra-pure)</td>
</tr>
<tr>
<td>Actuators</td>
<td>4 Pico-engines (Units 1 &amp; 2)</td>
</tr>
<tr>
<td></td>
<td>9 PZTs (Units 2 &amp; 3)</td>
</tr>
<tr>
<td></td>
<td>7 nano-engines (Units 2 &amp; 4)</td>
</tr>
<tr>
<td>End-effectors</td>
<td>3 + 1 substrate or the AFM console</td>
</tr>
<tr>
<td></td>
<td>4 AFM consoles</td>
</tr>
<tr>
<td>Desktop</td>
<td>18 mm x 18 mm x 12 mm x 360 ° (raw, pure)</td>
</tr>
<tr>
<td></td>
<td>26 mm x 22 mm x 35 mm (ultra)</td>
</tr>
<tr>
<td>Positioning resolution</td>
<td>30 nm (gross), 2 mrad (gross), 2 nm (pure), sub-nm (ultra-fine)</td>
</tr>
<tr>
<td>Detection system</td>
<td>FESEM (resolution: nm) and AFM console</td>
</tr>
<tr>
<td>Micro-nano-instrument system</td>
<td>FESEM Resolution: 1.5 nm</td>
</tr>
<tr>
<td></td>
<td>AFM Console                      Stiffness constant: 0.03 nN / nm</td>
</tr>
<tr>
<td>Micro-nano-fabrication systems</td>
<td>EBID FESEM Emitter: T-FE</td>
</tr>
<tr>
<td></td>
<td>CNT Emitter</td>
</tr>
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</table>

Integronic robotics is a sub domain of integronics in which integronic robots operate and interact in different "scenarios" with technical, scientific, biological, geographical, geological, production, astronomy, military, mathematics, physics, computer environments, etc., from simple to complex processes, in adaptive steps corresponding to the goals in society. Integronic Robotics links in a unitary and universal system the scientific structural, mechanical, electronic, computer, social, psychological, economic universe, etc., working together man-friendly for the production of goods and the provision of integrated and / or complementary activities for the existence of life.

The approach and dissemination of integronic robotics approach requires a complete understanding of the overall behaviour of components and equipment and integronic plants, as tangible part of a future integronic industry.

In essence, robotic integronics accumulates all technical and robotic technology, automation and computerization, artificial intelligence and neural sciences, physics, chemistry and mathematics, sociopsychological and economic management, leadership, coordination and monitoring as well as elements of ensuring environmental protection.

The evolution of robotic integronics has begun to take the first steps of the first generation of integronics, characterized as:

- "online" and "off-line" programmable robotics, integrated with sensors, actuators, artificial intelligence and neural network control with psycho-socio-economic monitoring;
- adaptive robotics and heuristic integrated with "superhuman intellectual and polyvalent capacities";
- genetic multi-vectorial robotics integrated with "fuzzy capacity";

The first development of the first generation of integronic robotics manifested in several developed countries worldwide, such as Japan, USA and Germany, proving the ability of the contemporary world, the integration of technical, scientific, human, sociopsycho-economic, sciences, in a complete and complex, versatile and poly-culture, science – the science of integronics.

Thus, the integronic science includes structurally and functionally in addition to robotics and integronic robotics / integronic micro-mechatronics, integronic computer science, integronic biotronics, integronic logistics management, leadership management of integronics, etc..

The analysis of integronic robotics as an important integronic sub domain and characteristic of the immediate future period deals with "increasing complexity and volume of interactions with the environment", because of this integronic robotic, assuming the following immediate aspects:

- implementation and further development of new sub-fields of new materials with nano-technical and
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nano-technological properties, with the capabilities and behaviour of the current upper and upper level;
- implementation and development of special micro-nano-sensors and sensors, with hybrid and super-function, components of integronic robotics;
- implementation and development of the structure, function, behaviour and adaptation of mechatronics and nano-micro-mechatronics micro-mechatronics, components of mechatronic integronics;
- implementation and development in the upper generations of biotronics, micro-biotronics and nano-biotronics, components of mechatronic integronics;
- implementation and development of logical-informatics, micro-logical-informatics and nano-micro-logical-informatics, components of mechatronic integronics;
- implementation and development of logical-informatics, micro-logical-informatics and nano-micro-logical-informatics, components of mechatronic integronics;
- implementation and development of logical-informatics, micro-logical-informatics and nano-micro-logical-informatics, components of mechatronic integronics;

The development of integronic robotics involves also punctual development of components and subassemblies of major importance, such as:
- constructive and functional approach to sensors / micro-nano-sensors and transducers / micro-nano-transducers with nanometre performance;
- constructive-functional approach to systems / control micro-nano-systems;
- constructive-functional approach to systems / micro-nano-systems for actuating and monitoring;
- structural approach and evaluation to systems / micro-nano-systems for leadership and management;
- structural approach and precision and nano-precise approach to precision devices / measurement equipment / regulation and control systems;
- structural and behavioural approach to systems / mechanical and micro-mechanical nano-systems;

- approach to the effect and impact of adaptive, flexible and special software;
- approach to the development of logistics and micro-nano-logistic, and overall decision-making activities;
- approach to environmental friendly behaviour;
- approach to the socio psycho-economic behaviour in "scenarios of designed space";

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