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Editorial

Micromanipulation: A Challenge for Actuation

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Received: 12 November 2018; Accepted: 29 November 2018; Published: 3 December 2018

Abstract: Manipulating micro objects has become an important task in several applications. Actuation is a crucial aspect of micromanipulation because there are physical restrictions which affect actuators' performances at the micro or nano scale. One way of getting rid of these limitations is the use of an appropriate mechanical structure which enhances the elasticity of the material or provides mechanical advantage. This Special Issue of Actuators, which is dedicated to micromanipulation, offers a contribution to the development of some promising methods to actuate a microsystem for micromanipulation.

Keywords: micromanipulation; nanomanipulation

1. Introduction

During the last decades, microsystems have been developing very fast thanks to progress in science and technology, giving rise to two main crucial questions, namely,

- how could these micro devices be fabricated and operated?
- how could they improve certain aspects of our lives?

The first question leads to classical issues of engineering, such as design, fabrication and control, which study the most convenient way to create the tools for micromanipulation.

The second question is clearly related to the applications of these new developed tools and to their exploitation, as an opportunity to solve old and new problems for the improvement of certain aspects of our lives.

1.1. Downsizing Effects

Once involved in the development of a microsystem, designers immediately come across the problem of handling the scaling effects. They soon become capable of monitoring how surface and volume properties change their impact on a system; once the latter is downsized by one or more orders of magnitude from the human-size typical dimensions: of course, surfaces or volumes will reduce their quantities by the square or the cube, respectively, of the reduced lengths.

Scaling effects were described by Galileo Galilei in 1638 [1]. He pointed out that "a large animal does not possess simply a bone on a larger scale, but its thickness must increase more quickly than the length of the relevant bone", because resistance and weight scale their quantities differently during downsizing. Similarly, "a giant would never have the same limb ratios of a man with a normal size, but he must have thicker limbs suitable to support its mass".

After about a century, Jonathan Swift described the voyage of Lemuel Gulliver [2] to Lilliput. In the book, the imaginary Surgeon, and then a Captain, reports, literally, that the Lilliputian "mathematicians, having taken the height of my body by the help of a quadrant, and finding it to exceed theirs in the proportion of twelve to one, they concluded from the similarity of their bodies, that mine must contain at least 1724 of theirs, and consequently would require as much food as was necessary to support that number of Lilliputian". Surprisingly, the mentioned human-to-lilliputian food ratio (1724) only approximates the square of 12 (1728) and, even more curiously, the year of publication of the book (1726).

1.2. Design, Fabrication, and Control

Design, fabrication and control of microsystems for micromanipulation have to face several difficulties because, at the micro or nano scale levels, several paradigms of macro-scale engineering are no longer valid [3]. These and many other consequences and implications have been early underlined by Richard P. Feynman, during his seminal talk given on 26 December 1959 at the annual meeting of the American Physical Society (APS) at the California Institute of Technology [4]. In this speech, Feynman surprisingly mentioned many applications such as computer miniaturization, microsurgery, micro-machining and actuation.

Nowadays, an increasing number of applications are demanding high-precision tools which introduce more and more constraints to their design, following the classical client-to-designer feedback.

The following issues have been particularly discussed in the literature.

- Micromanipulation mechanics [5–7]:

  theoretical modeling,
  numerical simulation, and
  experimental testing.

- Microsystems architecture, components and manufacturing [8–12]:

  design,
  fabrication,
  fabrication constrained design rules,
  packaging and
  biocompatibility.

- Actuation and Sensing [13–16]:

  electrostatic,
  electrothermal,
  electromagnetic,
  piezoelectric.

- Micro-electro-mechanical system (MEMS) integration:

  lab-on-chip systems [17–19],
  MEMS integration with Application Specific Integrated Circuit (ASIC) [20,21].

- Control [22–24]:

  automatic regulation and control of microsystems,
  operational aspects of micromanipulation,
  measurements.

However, while Nanotechnology has found a certain variety of good (although still perfectible) solutions to many problems in MEMS developing [25], what makes micromanipulation particularly difficult is its actuation. In fact, the available sources are often not able to exert an adequate force or torque. Furthermore, the highest performances are achieved only within a rather restricted range for end-effector displacements, and so the mechanical structure of the microsystem must be optimized. In fact, actuators are devices which transform energy (e.g., thermal or electrical, depending on the available source) in mechanical energy. Using the classical sources, such as electrostatic, thermal (shape memory, electrothermal), electromagnetic, or piezoelectric [26], it turns out that it is rather difficult to achieve both a large force together with a large displacement at the output link and, therefore, a micro mechanism can be employed to gain the mechanical advantage. Fortunately, recent developments in MEMS Technology allows designers to introduce different sorts of micro mechanisms, such as microgrippers [27,28], with multi-hinge and multi-DoF (Degrees of Freedom) properties, and other multi-axes devices [29]. Such opportunity gave rise to the introduction of a design technique based on the rigid-body replacement method [30], which refers to classical issues of mechanism science such as topology [31,32], kinematic synthesis [33–35], kinetostatic indexing [36], isotropic compliance [37,38] and parametric design [39,40].

1.3. Applications

Nowadays, micro or nano manipulation is very attractive in a large variety of applications, ranging from medicine, surgery or biology, to microelectronics, micro mechanics and aerospace. Therefore, the following items represent a non-exhaustive list of much more examples of applications:

- drug delivery [41,42],
- minimal-invasive surgery [43,44],
- tissue or cell manipulation [30,45–47],
- diagnostics [48–51],
- aerospace [52–54],
- micro-assembly [16,55–57], and
- microelectronics [58,59].

1.4. Forthcoming or Emerging Issues

Other than the above-mentioned classical issues, there are some others that are either more recent or, at least, less usual than the former. In fact, once new concepts become well-established and real devices, the interest in their optimization and use increases. Furthermore, some other related issues appear, and so the following topics could soon become new topics for MEMS and microsystem applications.

- Computational intelligence: optimization and control of microsystems [60,61].
- Development of ambient intelligence [62] based on sensors, actuators and standardized internet communication.
- Use of nonlinearity benefits [63,64].
- Configuration management and reconfigurable manufacturing systems for the development of microsystems during lifecycle [65].
- Ethics: ethical issues in the activities of criteria-based decision making autonomous micro-manipulators in the medical, biological, aerospace and industrial fields [66–70].
- Education: new trends in microsystems teaching–learning methods, tinkering, open access, wiki tools [71,72].

2. On the Variety of Demand vs. the Supplying Capability

A selection of 1846 papers concerning “micromanipulation”, distributed over seven different meta categories, namely, Biology, Computer Science, Engineering, Medicine, Multidisciplinary issues, Physics/Chemistry, Science have been analyzed. These categories have been named after the classification suggested by one of the most acknowledged database for Science and Technology, that is the Web of Science [73]. A series of queries has been launched on the database and some statistical data have been extracted. At the first sight, among the above mentioned categories, there is one which can be assumed to represent the “supplying capacity” at the actual state of the art, as introduced in Section 1.2, namely,

- Engineering,

The other six categories represent the variety of the demand of micromanipulation technology and its temporary success in applications, as mentioned in Section 1.3, that are

- Biology,
- Physics and Chemistry,
- Medicine,
- Computer Science,
- Multidisciplinary issues, and
- Science.

Statistical analysis has revealed that the struggling for technological readiness, that could be reasonably represented by the filed of engineering, collects almost a half of all contributions, about 45% of the papers. On the other hand, the applications, which could be thought as the "recipient" of the technological progress, gather the other half of the full bunch of papers. More in detail, the Biomedical Sciences, including Biology (18%) and Medicine (11%), form 29% of contributions. General categories such as Science (3%) and Physics/Chemistry (13%) form about 16% of the considered papers. Finally, Computer Science includes 6% of the selected papers, while the last 4% concerns multidisciplinary issues. Figure 1 illustrates the distribution of the selected papers according to the above-mentioned categories.

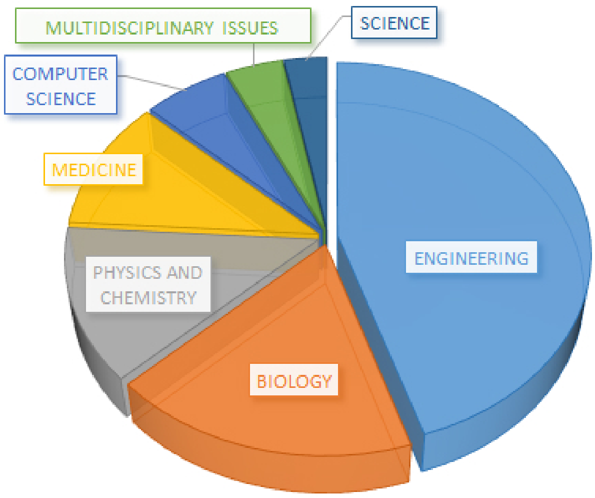

Figure 1. Statistical distribution of 1864 papers concerning "micromanipulation" along seven different groups, gathered over 83 Web of Science Categories.

The adopted method of paper selection has been based on classical database query tools, as implemented in WoS [73] and, therefore, the search keys, which consist of selected words, may be subject to double meaning errors. This introduces an error that can be roughly estimated by manually checking some elements extracted from a randomly sampled group. On the basis of a rough estimation, the mistake is expected not to exceed 3% of the values.

The results of the present investigation show that research into micromanipulation is still more extended in the field of engineering than in any of the other applicative fields. However, the full group of applications represents half of the analyzed papers, which shows that engineering vs. applications are nowadays in balance.

These results probably reveal the actual struggle of investigators to improve the technical characteristics from a rather low technological readiness level (TRL) [74], to higher TRL values that are more suitable for immediate and commercial applications. It is rather difficult to predict how much time it takes to make micromanipulation technology ready for more applications in hospitals, labs, cars, aircraft, appliances, and so on, while, on the other hand, it is easy to infer that the number of applications will increase as much as new confidence is acquired in the construction and control of the tools.

Figure 2. SEM image obtained by Alvise Bagolini and Michele Fedrizzi at Micro Nano Fabrication and Characterization Facility, Fondazione Bruno Kessler, Trento, Italy (PS the housefly has been found dead in Villamontagna, Trento, Italy and no harm has been inflicted to the poor insect).

3. Tools for the Observation

As known, the human eye normally barely distinguish objects within the size of a few tens of microns, which makes it difficult for us to monitor micro devices without a proper means of magnification. Usually, optical microscopy could give a first-hand tool for observation, with the advantage of operating in air or liquid environments. However, SEM observation is more helpful to characterize the prototypes, because of their higher resolution. For this reason, in MEMS development, the moment always comes, eventually, to take an SEM picture of a microsystem. Usually, an image obtained by an SEM instrument declares the adopted magnification factor and other technical data and, therefore, there is no real need to use a side comparison object (whose dimensions are universally known). At the macro level, classical objects can be used to compare the observed subject with familiar objects, such as a one cent coin or the portion of a ruler. However, while moving around either the "brobdingnag" or the "lilliput" worlds, it is not always easy to grasp the real sense of the size of an object which has unusual dimensions, such as gigantic (planets, stars, galaxies) or minuscule (cells, atoms) things.

Figure 2 is an example of a comparison exercise at the microscale. An adult housefly, musca domestica, was positioned over the square portion of a silicon wafer where a microgripper had been fabricated [12]. According to the construction process and the adopted parameters, each microgripper lays within a 5×5 mm^2 window, whereas adult houseflies are usually from 6 to 7 mm in size. That is why the whole insect was as long as the length of a microgripper window. The fly eyes, whose diameter is approximately one millimeter and a half, are visible at the top of Figure 2, while the microgripper shows up in the lower half of the picture. In the upper half of the figure, the compound eyes of the fly appear in all their complexity. In fact, there are almost 3500 ommatidia facets in the musca domestica' eye [75], while the single ommatidium is about 10 μm [76]. This figure make the microgripper a bit less mysterious object to our understanding.

4. Micro- or Nano-Manipulators vs. Micro- or Nano-Robots

Finally, it is worth noting that the terms micromanipulator and microrobot (the same holds for the pair nanomanipulator and nanorobot) are often used as synonymous, while it would be better not to confuse them that way. In fact, developments in technology have made it possible to build devices with different features; for example, their overall size or their positioning or manipulating accuracy.

Considering the scope of developing miniaturized devices at the bottom scale, it seems to be appropriate to refer to such devices as microrobots, micromechanisms, micromachines or, more generally, microsystems (nanorobots, nanomechanism, and so on). On the other hand, when a device (no matter about its size) is required to be able to manipulate objects with micro (or nano) accuracy, then it seems that the term micromanipulators (or nanomanipulators) becomes more appropriate.

This distinction is quite substantial. In fact, in many occasions, it is necessary to handle micro- or nano-objects, with limited concern about the size of the manipulating object. For example, nano-manipulators used inside the chamber of a Scanning Electron Microscope (SEM) may have extraordinary resolution, <0.5 nm, with rather a, relatively, large overall size, of about 6 cm [77]. On the other hand, in some other circumstances, it is necessary to have a small system, namely, a microsystem, which is able to operate within specific environments, with very restrictive size limits. Interest in miniaturizing micromechanisms [78], microrobots [79,80], microgrippers [81,82], and microtribometer [83] has been recently expressed. In fact, in all these examples. the size of the microsystem was fundamental for the performance of its function.

5. Conclusions

The present Editorial has been written with the intent of intriguing readers and colleagues who may want to deepen the topic of actuation at the microscale, specially for the purpose of micromanipulation. The actual state-of-the-art shows that this problem is rather far from being exhausted and, therefore, the present Special Issue represents an invitation to accept the challenge to find proper solutions to this endeavour.

Conflicts of Interest: The author declears no conflict of interest.

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