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MICRO ELECTROMECHANICAL SYSTEMS FOR AUTOMATION AND CONTROL: A BRIEF SURVEY

Todor Stoilov Todorov

Technical University of Sofia
e-mail: tst@tu-sofia.bg
Bulgaria

Abstract: This paper illustrates the great impacts exerted by micro electromechanical sensor and actuators which are produced to perform automation and control operations for industrial processes. More recent developments are discussed which suggest market prospects for MEMS devices. Some market data and forecasts are presented. The paper provides a technical and commercial insight into the applications of MEMS technology to automation and control devices as well as shows high growth for innovative developments in this area.
Key words: MEMS, sensor, actuator, automation, control.

1. INTRODUCTION

Micro electromechanical systems (MEMS) are highly integrated and miniaturized devices with high sensitivity and reliability. MEMS combine an advanced semiconductor or an innovative technology, which involve moving components as well as integrated circuits (ICs) on a single chip. The solutions with low cost technology have provided sensor and actuator devices for industrial automation with remarkable capabilities. The trend toward MEMS based miniaturisation and micro mechatronics supports the development of components, devices, and entire completed systems for industrial applications (Bhaskar and Menaka, 2007).

The same basic technology and process steps such as the photolithography, patterning, doping, and bonding are applied for making conventional ICs such as complementary metal-oxide-semiconductors (CMOS) can be used to fabricate micromechanical elements of a silicon wafer or adding new structural layers to form MEMS devices. However, there is a fundamental difference between MEMS and ICs devices - namely, MEMS devices must remain physically movable. MEMS devices use electronics to move their mechanical elements (Lau et al., 2010). This is typical for MEMS actuators, but for the microsensors the electronics is used to estimate the characteristics of the mechanical motion, to improve the detected signal and/or to tune some parameters of the electromechanical system. In the advanced microsystem sensors and actuators the electronics consist of hardware, which improves the device performance applying the software for monitoring and controlling the processes.

The low energy consumption of MEMS devices which varies from about 1 μW to few mWs, (Mateu and Francesc, 2005), makes them applicable in every surroundings and now it is possible to derive an autonomous energy source for MEMS almost from everywhere. The progress of wireless sensor networks in the direction to provide true ambient intelligence require the combination of knowledge in different disciplines: networking, low power RF and digital IC design, MEMS techniques, energy harvesting, and packaging (Otis and Rabaey, 2007).

The analysis of Frost & Sullivan, which point out the impact of MEMS sensors on control and automation shows that "MEMS-based sensors and actuators have experienced a slow yet steady growth in the industrial automation sector. As the industrial arena moves toward intelligent, distributed as well as wireless monitoring and control, MEMS technology will likely play an increasingly vital role" (Sankaranarayanan, 2009).

The paper is a brief survey in the field of MEMS which involves the advanced sensors and actuators for industrial automation and control.

2. AUTOMATION AND CONTROL MEMS MARKETS

Innovative processes are at the basis of the growth of the MEMS material and equipment market. Yole Développement forecasts "that demand for MEMS-related equipment will grow from ~ $378M in 2012 to > $510M by 2018, at a compound annual growth rate (CAGR) of 5.2% over the next five years". "It's interesting to note that all MEMS equipment market forecast will follow a cyclical up/downturn similar to what the mainstream IC equipment market underwent". The needs for MEMS materials "will grow from ~$136M in 2012 to > $248M by 2018 at a CAGR of 10.5% over the next five years" (Mounier E. and Pizzagalli A., 2013).

Nowadays MEMS technology is "still very much diversified and lacking in standardization"; Yole Développement's rule "one product, one process" still applies. Furthermore MEMS have a different streamline than IC and do not going to follow the same technological progress. It can be seen many producers with different manufacturing processes for the same MEMS device. Sometimes it happens within the same company. For instance both the CMOS MEMS and hybrid approaches can be used for inertial devices or for pressure sensors and microphones (Mounier E. and Pizzagalli A., 2013).

The MEMS global equipment and materials demand is shown in figure 1. The graph shows relatively stable growth of the material market costs but the equipment market costs according the forecast will grow and at the end of 2018 will be same as this in 2014.

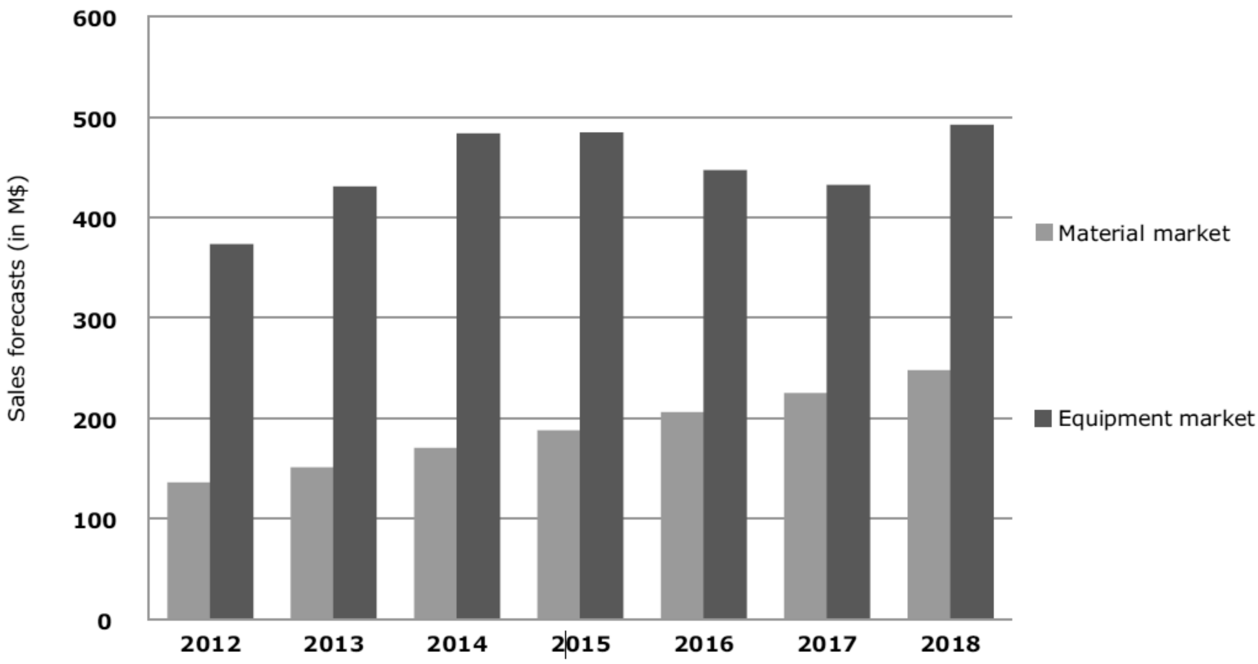
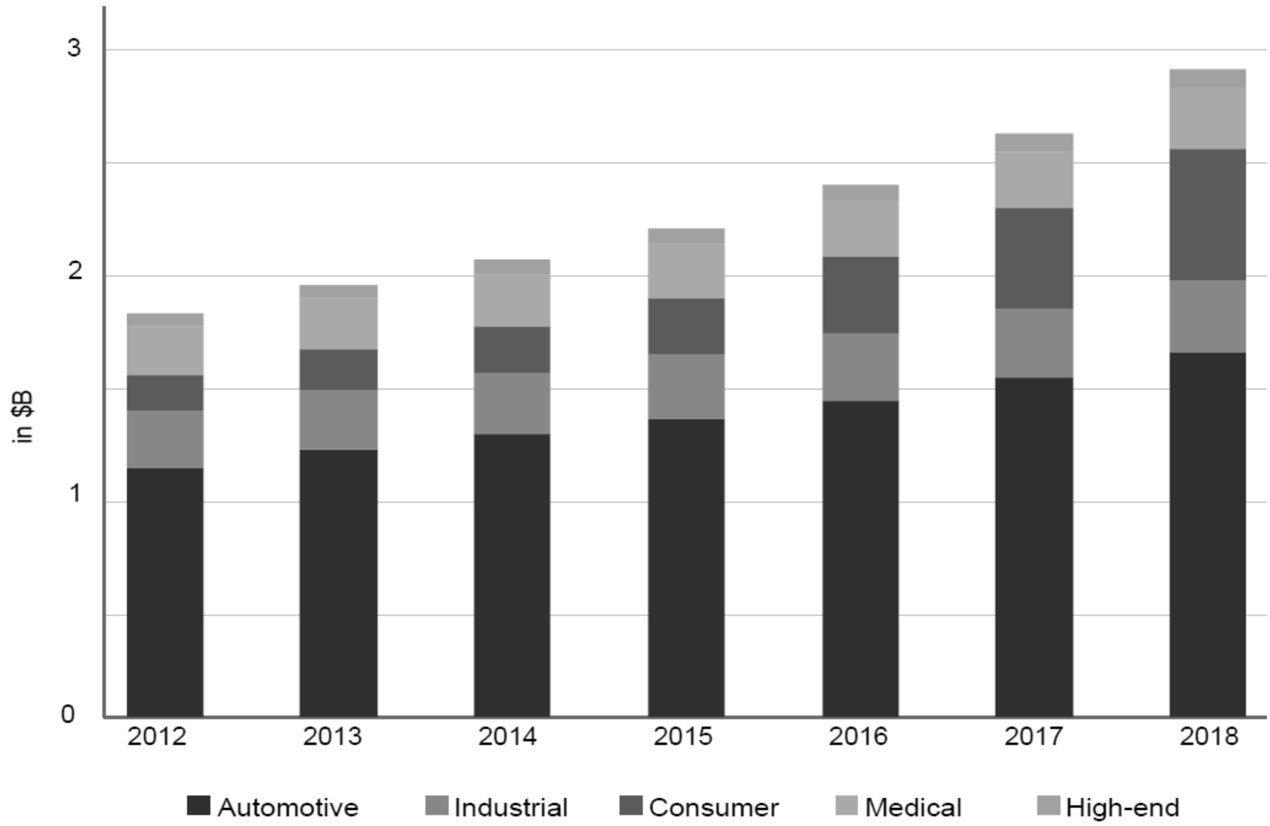


Fig. 1. MEMS' global equipment and materials demand (Mounier E. and Pizzagalli A., 2013).

Historically the pressure sensor is one of the first batch produced MEMS device. Nowadays the technologies for such type devices are mature enough and the market as it is shown in Figure 2 "is big and expected to grow from $1.9B in 2012 to $3B in 2018" (Ding W., 2013). Yole Développement predicts that "the global volume of the MEMS pressure sensor market hitting 2.8 billion units by 2018. Consumer pressure sensor will represent 1.7 billion units and will overtake automotive as the market leader in volume. The promising segment for pressure sensors will bring more than 8% CAGR to the global MEMS pressure sensor market" (Ding W., 2013).

In Figure 2 we can see that the pressure sensors for industrial applications is about three time less than the automotive pressure sensors but they are at the second position. As the automation and control devices, the pressure sensors take part in hydraulic systems, HVAC in industry and buildings, gas analyzer and meters.

Pressure sensor technologies vs. suitable applications and pressure ranges are represented in the Figure 3. The analysis of the graph shows that the MEMS capacitive silicon sensor is not suitable for industrial application. Piezoresistive pressure sensors are one of the favorites for such application. At the similar position are the ceramics capacitive pressure sensors. The thin film pressure sensors are also widely appropriate for industrial applications but for the higher range of the measured pressure.



Фиг. 2. MEMS pressure sensor market forecast by applications 2012-2018 (Ding W., 2013).

MEMS accelerometers are more widely known in the car airbag safety systems. The deceleration of a car is sensed during the impact and the accelerometer has to deploy the safety system of the car. Because of the deflection in the impact zone the deceleration can be very high but the change of the velocity of the passenger can be low. The accelerometers in safety applications measure from 35–50 g of amplitude and 400 Hz of bandwidth which is filtered. In measuring crash results the transfer function that includes the mounting of the accelerometer in the module is important as many printed circuit board configurations can have Qs of over 30 at frequencies above 400 Hz and can create signals that appear as decelerations in the range of interest (Huikai at al., 2008).

The accelerometer sensor has wide applications in automation and control systems as active vibration control (AVC), machine performance monitoring, instrumentation robotics (fig. 4). As it is shown in the Figure 4 for automation and control some of the widely used accelerometers are this one which are applied in machine monitoring. The price of such devices unusually rages from 6 to 15 $. This low price can be explained by the relative low requirements with respect to the reliability, bandwidth and the precision.

The Inertial Measurement Units (IMUs) consists of 3D accelerometer, 3D MEMS gyroscope, 3D magnetometer or compass and temperature sensor. The IMUs are used to improve the navigation and stabilization of moving objects in the space.

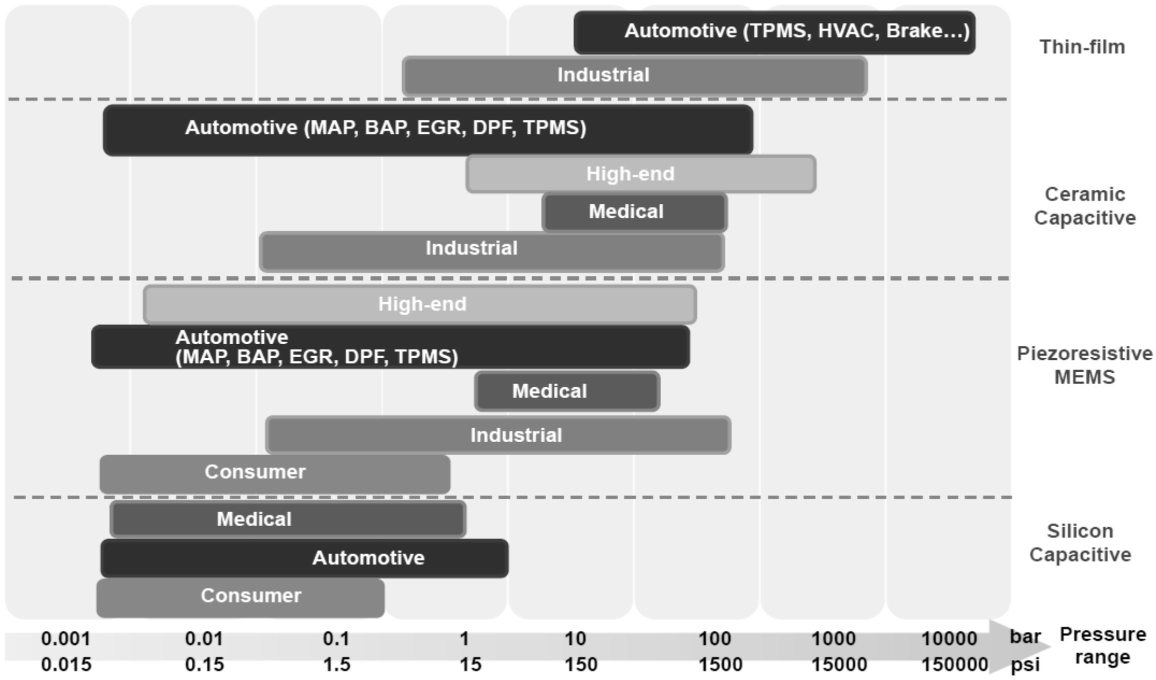


Fig. 3 Pressure sensor technologies vs. suitable applications and pressure ranges (Ding W., 2013).

Although the platform stabilization and instrumentation robotics accelerometers require the same bandwidth and precision, the reliability and the working range requirements increase their cost.

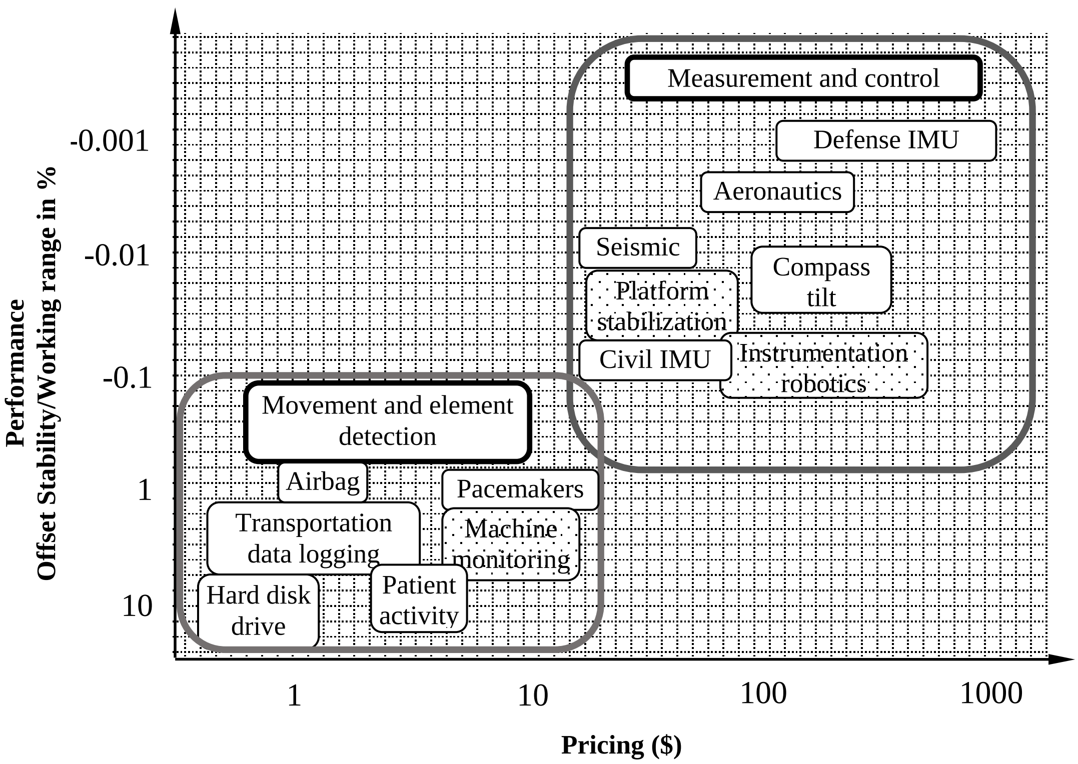


Fig. 4. Representation of accelerometer market (Huikai at al., 2008).

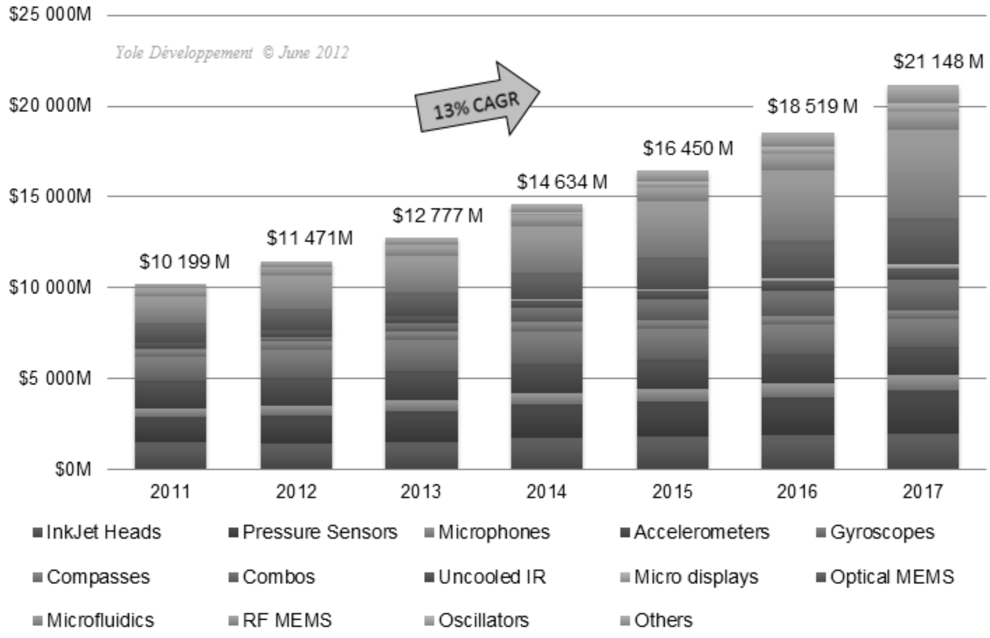


Figure 5: 2011-2017 MEMS markets in US $M value (Mounier E., and Robin L., 2012).

As it can be seen in Figure 5 depending on the type of device, CAGRs range from 1% to more than 90% after Yole Développement (Mounier E., and Robin L., 2012). Some data, which presents the number of the fabricated units till last year, is shown in Figure 6.

As it is well known although every type of sensor and actuator which is shown in the figure can be applied for automation and control processes (Lindroos at al.,2010).

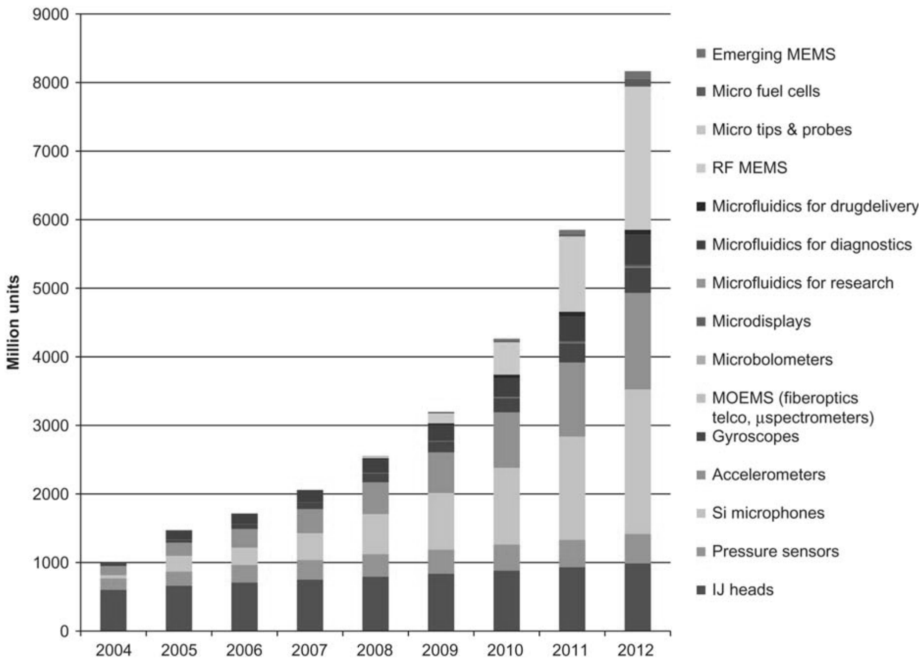


*Figure 6: The estimated MEMS market trend by the Yole Développement (*Lindroos *at al.,2010).*

3. TRADE-OFFS AND RESEARCH TRENDS

One of the most important for MEMS development is material research and technology (Higuchi et al. 2010).

The piezoelectric materials have been studied from decades but some challenges still remain. The researchers now try to increase the transduction level and corresponding stroke by means of single crystal piezoelectric ceramics. In shape memory alloy (SMA) microsystems one of the trends for the future is the improvement of material properties in terms of fatigue by means of either training processes or ternary additions to the basic NiTi alloy. The tailoring of material characteristics to suit the application is another trend. This involves the control transformation temperatures and their relative position. This is expected to have a considerable impact on the applicability of SMA actuators in the automotive industry (Higuchi et al. 2010).

Another trend in research is the combination of different transducing processes.

For piezoelectric materials it involves magnetopiezoelectricity and photostriction. New actuation mechanisms in addition to the classic tensile, bending or torsion concepts are not enough applied in SMA systems. Research for active devices that will exploit the self-sensing capabilities of SMA actuators, their intrinsically high force density and their compact configurations is the next scientific direction (Higuchi et al. 2010).

An open field of research is the application of new actuation configurations. For example the resonant SAW actuators include the efficient combination of different resonant modes in which to render actuation mechanisms. Such investigation, in particular, has been made already (Yanchev, 2012). The pursuit of new composite approaches will be next research area in the future although it has been used in the past research (Zhao et al., 2012).

The improving of control in order to exploit fully the actuation features of sensors and actuators is the next direction of development. For example the magnetostrictive (MS) actuators need to be better integrated in control loops. It is necessary to be improved the utilization of the self-sensing capabilities of MS actuators, their integration in collocated sensor actuator approaches and in the pursuit of new applications that exploit the change in Young’s modulus, resonance frequency and other allied phenomena (Higuchi et al. 2010).

The utilization of new micro actuator and sensing operational principles is one of the most important direction of MEMS development. For instance creating novel actuators based on functional fluids is an advanced direction. This involves: electro-conjugate fluids that generates jet flow in inhomogeneous electric field; electro-rheological fluids that change the viscosities in electric field and magneto-rheological fluids in which the viscosity is changed by magnetic field (Pons J. 2005). The extreme efficiency of producing bubbles via electrolysis of water has been put to use in a new design for MEMS sensors and actuators (Alexandros, 2000).

4. CONCLUSION

Although the earlier micro electromechanical systems for automation and control came into the market in earliest 80th of the past century and they have had his remarkable growth since 1990, the market trend shows that this devices are in its initial stage of development.

The most important tendency of development of these devices in nowadays are: material search and technology; improving the transducing principles and creating the novel ones which are not known in the world of the micro devices yet.

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