Automatic Control of Physiological State and Function

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Comparative Functional-Structural-Power-Sensing-Intelligence-Dynamic Task- Environmental Study of MIS Robotic Systems Complexity

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Abstract

The prevalence of MIS robotic technology has increased in such a way, both in the social, health and economic aspects, that it is extremely important to have valid and generally accepted ways to measure the complexity of the very diverse technologies. In the beginning of the second decade of this XXI century, we are experiencing a new technological revolution in the way surgery is offered all around the world. We can say that we are probably living in the beginning of the Third generation of MIS technology where functionality and security are no longer the predominant criteria to qualify a new robotic system for medical use. We are seeing since the end of the 2000's how new projects are trying to justify the change between the current haptic approach of multi-input Multi-output robust static out vivo machines with various actuators, each one with many degrees of freedom, to a new approach using a network of many mini-robots with few actuators. It is strongly necessary to develop measures of comparison of the different MIS robotic systems in terms of functional, structural, sensing, intelligence, interface, and dynamic task, environmental and power complexity, applicable to any machine system. A complexity comparison study of this kind, must involve a way to determine levels of complexity that can be computed from design parameters of any robot. This qualitative study aims to fill the gap that is the lack of objective measures of complexity used to describe features of these machines.

Keywords: MIS technology; Robotic systems; Surgery; Sensing

Introduction

At present the market of MIS robotic technology has increased its importance in such a way, both in the social, health and economic aspects, that it is extremely urgent to have valid and generally accepted ways to measure the complexity of the very diverse technologies. We aim to provide orientation to physicians, hospitals, insurance companies, and universities on how to decide between surgery robots in the face of such a crucial financial decision.

The beginning of the second decade of this XXI century is experiencing a new technology revolution in the way surgery is offered and practiced all around the world. There is a clear trend in the past decade that these once seen as luxurious solutions are becoming accessible to almost everyone that needs them.

We can say that we are living probably in the beginning of the Third generation of MIS technology. Functionality and security are no longer the predominant criteria to qualify a new robotic system for this use, but also ergonomic considerations, like comfort, portability or compatibility, as well as economical ones, and the possibility to optimize the waste of time, energy and work-specialist hours, or to how to accelerate maintenance, cleaning and sterilization routines is so crucial to decide in between one or other choice in the market.

We are seeing, since the end of the 2000's, how new projects in MIS proposed by universities and private companies are trying to justify the change between the current haptic approach of surgery robotic Technology, based on multi-input Multi-output robust static out vivo machines with various actuators, each one of many degrees of freedom, to a new approach using a network of many mini-robots with few actuators, each one with small number of degrees of freedom, and locomotive ability acting *in vivo* not only on the body but even inside the human body (Figure 1).

This urge of change is not stopping with these new proposals, but even is running at a so fast pace that there are also many futuristic ones projected to be refined before this decade ends, that will reduce the sphere of the MIS to the nanotechnology dimension.

Problem

There has not been a better moment to find the way to give clear orientation to the public interested in this important segment of

Figure 1: Mirosurge robotic system.

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the health sector than this one. It is strongly necessary to develop measures of comparison of the different MIS robotic systems in terms of functional, structural, sensing, intelligence, interface, dynamic task, environmental and power complexity, applicable to any machine system, in spite of its size or if it is centralized or distributed.

The complexity comparison study of this kind, might involve a way to determine levels of complexity that can be computed from general parameters of design of any robot, for example: number of actuators, degrees of freedom of each one, size of work space of each one, precision gained by reducing the actuators size (dimension of torques), enhanced capacity to develop the required angular velocities given a time span by dealing with smaller inertia moments, reduced size of the algorithms to solve systems of equations for inverse kinematics which are needed to reach the operation points.

We are dealing right now in the world, from the recently occurred outbreak of Ebola in Western Africa that makes us remember at the same time what happened in 2009 with H1N1 or in the 1980s with AIDS, with a kind of explosive and really difficult to prevent health crisis. This is clearly showing that there exist situations, when dealing with devastating calamities or extremely contagious conditions, for which the use of Tele controlled medical robots of lower cost to assist not only surgery procedures but even diagnostics and any other medical preventive therapies, is probably the only real solution.

Extreme cases like these are such that the only solution that can guarantee a real possibility of success in providing fast, accessible, high quality attention, saving lives of a thousands of patients, controlling on time disasters of preventing pandemics, while also protecting the medical and paramedical personnel of professional risks, that no other kind of technology can offer with the safety and efficiency required.

Motivation

This qualitative study is looking precisely to fill the gap that exist as the lack of research developing a study based on objective measures for features of machines from a very impartial perspective, not linked with the interests of any manufacturer or provider of these services in the market (Figure 2).

Here we aim to develop a seminal research in this area, not trying to say the last word, but to generate motivation, interest, and discussion on the potential for advancement in MIS technology.

One of the most important applications that can be derived from this is to help to determine the cost-pay off relationship returned by several of the most famous MIS robotic systems that have captured the attention of the market during last 15 years.

Another important possible application is to show some of the relevant efforts that exist at present to improve this technology, the problems are dealing with and finally to explain challenges that only at future can be conquered by the third or fourth generation of MIS robotic systems.

The Results

Through exhaustive comparative research on the characteristics of a great variety of MIS robots, the following are the comparisons done and the observations that resulted from them arranged with respect to each one of the most important factors that might be considered when making a decision regarding the acquisition of one these machines (Figure 3).

Degrees of freedom classification of minimal invasive surgery robots

The ability for a robot to perform independent motions in one or more directions is called the degrees of freedom and constitutes an important characteristic that can emulate, through a robotic arm and its end-effector, the motion of the human hand. In a very simplified approach it is said that the human hand has at least 7 degrees of freedom.

The Degrees of freedom of the robots in study are as a follows:

Robots of 2 dof: Acrobot arm [1], Evolap (manipulator) [2], Heart lander Omni (rotational dofs) [3].

Robots of 3 dof: Clem [4], Kalar (2 for internal bending motion and 1 for external linear motion) [5], Naviot (among the two arms) [6], Viky [7].

Robots of 4 dof: blue dragon (2 for left robot and 2 for right robot) [8], fips endoarm (3 in propulsion unit) [9], Mako Surgical (4dof version) [10], MC2E (2 in compact spherical base and 2 in Trocar) [11].

Robots of 5 dof: Robodoc (2 on the wrist) [12,13].

Robots of 6 dof: Acrobot end effector [14], Active Trocar [15], Artemis [16], Mars [17], Mirosurge (with 3 in Mica instrument) [18],

Robots of 7 dof: Davinci [19], Mako surgical (7dof version) [20,21].

Robots of 8 dof: Black Falcon [22].

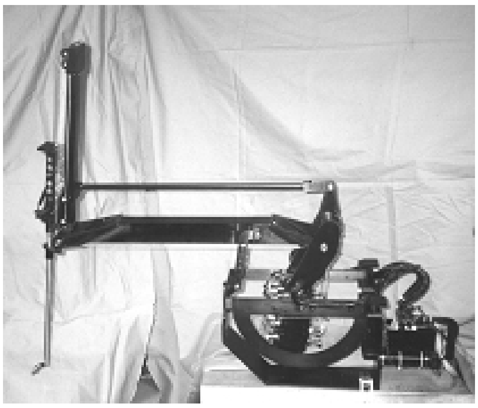

Figure 2: Black falcon robot.

Figure 3: Davinci robot.

Robots of 105 dof: Cardioarm (along its entire body) [23] (Figure 4).

Classification of MIS Robotic systems according with the types of surgery intended for

Although the manufacturers are working to give more areas of application to the respective machines, and many claim to be designed to perform surgery in general, being periodically tested into new treatments to get the clearance from the FDA, it is evident that there are areas of specialization in which each device has shown efficiency, precision, better use of time and the human factor into develop more operations than the ones took place when only manual techniques were available.

Here there are the different areas of specialization of the MIS robots in this study:

Orthopedic surgery: Mars (spine) [17], Acrobot [24], Mako surgical (knee) [25], revision THA, and Total Knee Arthroplasty) [12,26] Active Trocar [27], Robodoc (Hip Arthroplasty (THA),

Endoscopy Surgery: MC2E [11], Active Trocar [27], Blue dragon [28], Black Falcon [29], Clem [30], Fips endoarm [31], Mirosurge [32].

Laparoscopy Surgery: Black Falcon [33], Davinci [34,35], Evolap [36], Kalar [37] , Naviot (sympathectomy, cholecystectomy, splenectomy) [38,39], Viky (laparoscopy, coelioscopy and thoracic surgeries) [40].

Urologic-Gynecologic surgery: Davinci (Laparoscopic Radical Prostatectomy, Robotic Nephrectomy (kidney) [41,42], Robotic Cystectomy (bladder), Robotic Adrenal Gland Surgery).

Cardio Thoracic Surgery: Black Falcon [43], Cardioarm [44], Davinci [45,46], heart lander Omni [47].

MIS robotic systems with force sensing, touch sensing and audio feedback

All robots that are in this study have position sensing that operates either from the visual feedback or from a computational coordinate's orientation system and respective memory.

However, as a part of this primary feedback, some of the robots in study show to have haptic feedback (touch sensing), force feedback and even audio feedback.

Each of these 3 additional senses provides essential information to the surgeon to verify the results of the process, as well as to determine risk factors and reactions of the patient.

Touch sensing: Active Trocar [48], Blue Dragon [49], Cardioarm [50], Fips endoarm [51], Mako surgical [25], MC2E [52], Heart lander Omni [53], DLR-Mirs [54].

Force Sensing: Clem [4], Blue Dragon [8], Acrobot [55], Black Falcon [56], Cardioarm [57], Davinci [58,59], Fips endoarm [60], Mako surgical [61], Robodoc [62], MC2E [63]

Audio feedback: Mako surgical [62] (Figure 5)

MIS robotic systems with tremor-tilting filtering

Tremor or tilting of the surgeon's hands is a frequent problem in manual surgery as a consequence of cumulative fatigue resulting from many hours of continuous work. Of course this is a major problem that can affect, in a very risky way, the performance during an operation and fortunately this technology provides, using filtering of the signal, expurgating it of any undesired noise, a way to fix it.

Robots with Tremor-tilting filtering: Davinci [64], Fips Endoarm [65] (Figure 6).

MIS robotic systems offering capacity of tele-operation through master slave architecture

Robot assisted Minimal invasive surgery is at present offering a revolutionary technology that allows the surgeon to operate on patients from a distance by decoupling the systems into 2 modules: a control console (the master) where the surgeon can activate the motions of the machine assisted by the feedback signals arriving from the slave module (the slave) that is located in direct contact with the patient and possibly at a relatively long distance of the master. The tele-operation can be driven using telecommunications by signals or just cable driven, so it can be from some meters until perhaps hundreds or even thousands of miles far away.

The systems that offer the tele-operation possibility through Master Slave are, grouped by the type of master used:

-3 dof Phantom omni: (Sensable Technologies, Cambridge, Mass,USA) Active trocar [66], Blue dragon [67], Black Falcon[68], Evolap [62], Mars [69], Viky [70] -Monsun (manipulator control system, utilizing network technology): Artemis [16], -Other Master devices: Davinci master console [71], Mirosurge Sigma 7 control

Figure 4: Acrobot robot.

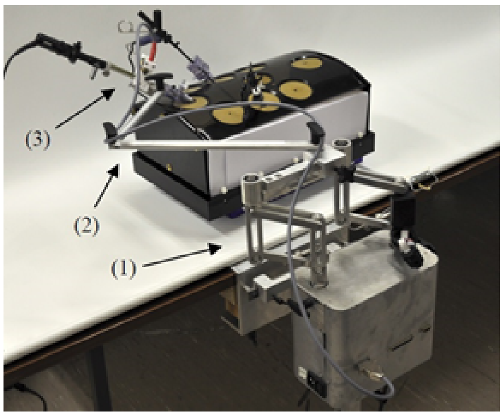

Figure 5: Evolap robot. (1)Remote Manipulator (2) the passive arm (3) A local zoom device.

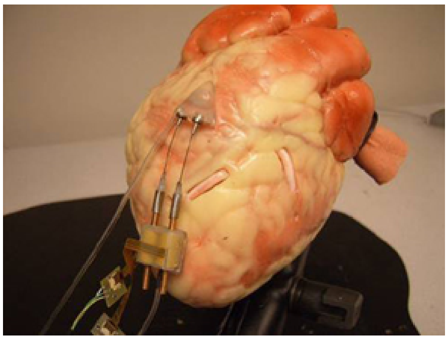

Figure 6: Heart lander omni robot.

interface [72], Orthodoc presurgical work station for Robodoc [73] -Microcomputer console: kalar [74] -Control driven tele-operated: Mako surgical [75], Black falcon, Viky [76] -Remote controlled : Naviot [77].

Classification of MIS robotic systems from the point of view of role and of automation

The fact that a robotic system has full powered actuators, that is to has motors activating them, is what distinguishes an Active surgery robot from a mere passive manipulator. A manipulator is basically a device that transfers the force of the hands of the surgeon to the exact point of operation but preventing the direct contact in between his hands and the patient's body.

One reason to use a manipulator is to have a frame that clearly constrains or bounds the area of operation and in that sense assures that other tissues are not affected nor damaged by the procedure. At the same time a passive manipulator provides a way to aid in the operation especially during surgeries performed without any nurse or medical assistant. The machine can even hold the surgery tools in a precise position during the operation to allow the physician to rest and check other equipment that provides important feedback regarding the patient's vital signs. In this last role the manipulator is acting as a positioner of the surgery tools.

Now, in some specific surgeries, it is required that a medical robotic system performs as an active machine at certain moments of the operation procedure, but at other instants allows the surgeon to be the active agent. This feature means that the robot has the ability to be in the two roles and it is said then that it is a synergistic one. The possibility that the robot becomes an automat means that the surgery process is not all the time under the control of the surgeon and that it can be pre-programmed at certain point to allow the automat to go ahead by itself, but also that the robot can have artificial intelligence. In this case anyway the surgeon might be always in position to interrupt the automated session and regain the control of the process if he considers is in benefit of the best results of the procedure (Figure 7).

From the point of view of Role the surgery robots in this study can be classified as:

Passive: Blue Dragon [78], Fips endoarm (remote controlled) [79]

Active: Active trocar [80], Artemis [81], Black Falcon [82], Cardio arm [83], Heart lander Omni [84], Kalar [85], Naviot [39], Robodoc [86], Evolap [87], MC2E [54]

Synergistic: Acrobot [30,88], Clem [87], Davinci [88], Mako Surgical [89], Mars [90], Mirosurge [7], Viky [91]

From the point of view of Automation, the surgery robots in study can be classified as:

Fully automated: Cardio arm [92], Kalar [93], Robodoc [94]

Semi-automated: Active Trocar [95], Artemis [96], Black Falcon [97], Davinci [98], Fips endoarm [99], Maco Surgical [100], MC2E [101], Viky [102], Heart lander Omni [103].

No automated: Acrobot [104,105], Blue Dragon [31], Clem [90], Evolap [36], Mars [17], MiroSurge [106], Naviot [38] (Figure 8).

Classification of MIS robots in study from the point of view of assistants and surgeons required to manipulate them

There are Robots that due to its portability, and very ergonomic design, facilitating great freedom of motions for the surgeon in the operation table and relative automated or semi-automated control, as well as their active or synergistic role in the procedure, provide the possibility to perform a Solo Surgery. A Solo Surgery is the one in which only the robot acts as the only assistant of one surgeon that operates alone during the entire operation without the need of more human assistants.

Solo surgery robots: MC2E [53], Naviot [107], Viky [108], Robodoc [109], Kalar [110], Heart lander Omni [111], Fips endoarm [112], Davinci [113]

Surgery robots requiring 1 or more Assistants/2 or more Surgeons: Mirosurge [72], Mars [69], Mako surgicall [25], Evolap [36], Clem [58], Cardioarm [83], Black Falcon [114], Blue Dragon [115],Acrobot [12], Active Trocar [15], Artemis [81].

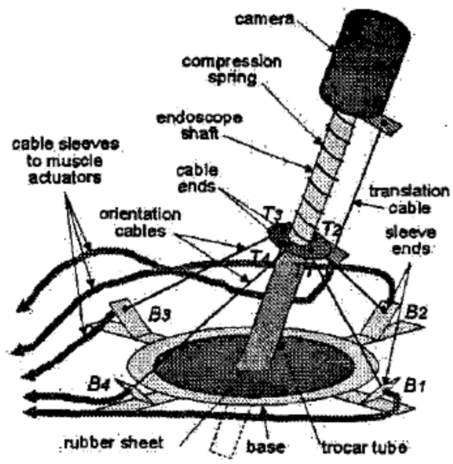

Figure 7: Clem manipulator.

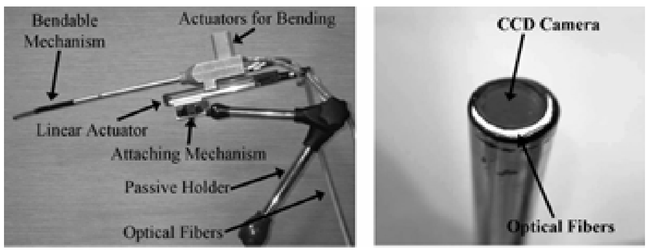

Figure 8: Kalar manipulator.

Classification of MIS robotic systems in study from the point of view of compactness of the equipment

The portability of a minimally invasive surgery robot is a feature that represents a very important aspect when dealing with limited space of work, like the one occurs in small clinics, medical centers located in small cities or towns, or even in medical emergency services corresponding to field plants of industries that are located in relatively isolated places, far from any urban center, as it happens for instance with oil refineries, mines, power centrals, big factories. Of course surgery in military scenarios can be counted in this category when it refers to first aid attention for injured soldiers directly at battle fields.

In all those different circumstances a very robust robotic system appears as an option that is not viable to solve the medical needs. So this makes extremely important the classification of robots into two principal groups:

Compact MIS robots: Naviot [12], Blue Dragon [115], Active Trocar [116], Heart lander Omni [117],Artemis [16], Cardioarm [45], Clem [91], Evolap [36], Black falcon [118], Fips endoarm [9], Kalar [119], Mako Surgical [120], Mars [17], MC2E [53], Mirosurge [121,122], Viky [7].

Large MIS robots: Davinci [123], Acrobot [124], Robodoc [125] (Figure 9).

Figure 9: Viky robot.

Classification of MIS robotic systems, according with force and motion scaling as essential ergonomic features

The capacity to offer motion and force scaling is also very important to enhance the precision of the actions of the surgeon, since in that sense it is possible with a minimum effort to get the results that are planned. These features are critical especially on long operations, but also on medical centers or clinics that are subject to a relative high transit of ambulatory patients, as is the case of urgent care sections of the big Hospitals in a modern metropolis, as well as it is the case of military hospitals that are receiving a great flow of injured people from the battle fields. After hours of work the surgeons usually start to feel the effect of the fatigue and this can interfere with their performance.

Among the robots that were checked in this study, these are the ones with motion and force scaling:

MIS robots with force scaling: Active Trocar [15], Fips endoarm [9], Mirosurge [74], Black Falcon [22]

MiS robots with motion scaling: Active Trocar [15], Artemis [126], Black falcon [22], Davinci [126], Mako Surgical [127], Fips endoarm [65].

MIS robots with no scaling features, just transmission ones: Acrobot [128], Blue Dragon [29], cardioarm [129], clem [130], evolap [36], Heart lander Omni [131], kalar [5], Mars [17], MC2E [11], Naviot [76], Robodoc [131], Viky [69] (Figure 10).

Figure 10: Blue dragon.

Classification of MIS robots that respond to hands free command units

The control systems that are implemented over the surgery robot represent a really important ergonomic feature of the MIS equipment. A robot that can be controlled only using manual commands might be very useful when it is desired that the surgeon work all the time actively in the surgery. However, when the intention is to develop a synergistic work, giving the robot responsibility for certain tasks that must be executed automatically, this constraint of performance would not provide the same level of freedom for the surgeon than the one that responds to voice commands, letting his hands to be all the time involved in to perform the part of the operation he must develop by himself, augmenting in the need of personal to assist in the operation room.

Voice control: Clem [4], Fips endoarm [31,132], Kalar [133], Naviot [38,134], Viky [7]

Foot pedal: Davinci [135], Viky [114]

Tool switch: Fips endoarm [136], Naviot [86]

Haptic controls console: Acrobot [136,137], Artemis [15], Black Falcon [42], Davinci [138], Mirosurge [72]

Computer driven keyboard: Heart lander Omni Mako surgical [92], Mars [69], Robodoc [138].

Mechanical handle: Active trocar [107],MC2E [53], Viky [7]

Head movement control: Clem [4]

Joystick control unit: Clem [90], Evolap [36], Fips endoarm [9] , Heart lander Omni Naviot [39]

Visual servoing control: Kalar [5].

Present problems of the MIS medical robotics

There is a trend to improve ergonomic features of the equipment, to make it not only functional but also comfortable to work with, giving the surgeon a workspace in which to reach exhaustion become every time a more remote possibility. (Artemis, Evolap, Davinci, Fips endoarm, Mirosurge)

Another important trend is to try to reduce the number of assistants and surgeons required for the operation room while working with the MIS robotic system. Ideally the goal is to reach a point in which the robot itself becomes the only assistant of a single surgeon working in a solo operation. (Davinci, Fips endoarm, Kalar, MC2E, Naviot, Viky)

Some Robots at present provide a lot of capabilities to adapt to any possible requirement but they are still very expensive for the great majority of the medical centers or hospitals around the world. One possibility to make these machines cheaper is through the specialization, that is, offering equipment designed for certain specific procedures, and in that sense reducing the number of features present in any machine of general purpose. (Viky, MC2E, Naviot, MARS, Kalar, Heartlander Omni, Fips endoarm, Cardioarm, Active Trocar) (Figures 11 and 12).

Another way to reduce cost is through the development of biocompatible new materials that can be used with less significant investment, materials that perhaps could offer good mechanical properties but at the same time which manufacturing become cheaper. One possibility is the substitution with plastics of many parts that at present are only produced with metals.

The contraction of the market due to the Great Recession of 2008-2010, as well as the current fierce competition among brands, has shown that many medium size or small producers and even sometimes

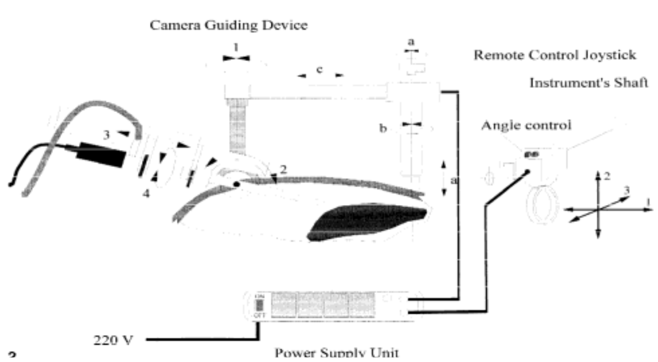

Figure 11: Fips endoarm robot.

Figure 12: Robot mako surgical.

important producers of MIS robotic technology couldn't continue operating in the market creating a tremendous issues for the clinics or Hospitals that were using them in their operations (Caspar, Zeus, Aesop, Hermes, Puma, Lars). Zeus is perhaps the critical case since although it was the very first MIS robotic system ever used in tele-surgery, and also one of the brands that more years remained in the market, became out of any possibility of to continue in use due to a lawsuit.

A new legal frame that regulates the market of MIS It is also strongly required to be developed. New laws on MIS technology market can control the negative impact that a conflict of interests in between different brands can cause to the patients or hospitals that are using their technology (Figure 13).

For instance, the legal battle in between Intuitive surgical and Computer motion put thousands of users of the Zeus and Hermes Technology in the grave situation of to be forced to close or interrupt operations. A new legal frame must contemplate that these cases can emerge and how to deal with them in order to assure that always the equipment that is in use must continue working it does not matter which provider or company owns the industrial property or patents involved.

Standardization is also a critical and very important step to follow if we want better robots and at lower cost. Developing clear quality standards that rule all the MIS sector of the industry could create possible bridges of compatibility among different products, making easier for hospitals and clinics to acquire gradually the robotic equipment they require.

Standardization is also very important to prevent the possibility that robots that are still functional and so useful in many Medical centers become obsolete just due to the fact that the original manufacturer closes operations. With general standards there could be always various providers in capacity to assume the maintenance or repair of old robots, independently of their original manufacturers.

Future trends of the MIS medical robotics

The use of biocompatible plastics in some parts of the surgery robots, for instance the tools attached to the end effectors, can send us to the era in which the sterilization of the equipment can be more rapid and simple. Cheaper parts of this type could even be disposable ones, used only with one patient and in that way avoiding the loss of time and energy that is supposed to send the entire machine to the autoclave sterilizer after each operation.

Reduction of costs can be also reached through reduction of size, to develop robots that can be in some way inserted in the body, of very small scale, and perform surgeries with tools and arms of smaller dimensions working exactly on the organs or inner tissues.

The miniaturization of MIS robots is now already on course, but it is possible that in a decade or so, nano robots will be ingested like pills by the patient and doing entire operations or applying some kind of medical treatment in very specific parts of the body.

Haptic MIS robots are at present the most important part of the offering of technology in the market, however, new more portable and economical technologies, like the nano robots and the mobile mini MIS robots are opening now horizons for sectors those in the past were unable to acquire MIS equipment. Important research in this area has been developed by Nebraska University, Carnegie Mellon University and University of Pittsburgh (Figure 14).

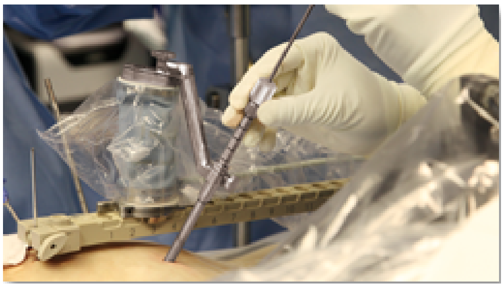

Figure 13: Mazor spinal surgery robot.

Modularity is another possibility to make more accessible the surgery robotic systems for many small clinics around the world. The idea is to offer to customers dedicated MIS robotic units for very specific tasks, the ones that can be bought separately. This is still a new trend in the industry, but there are now important first steps to implement it by certain new manufacturers (like Viky of Endocontrol, Vesalius, CoBRASurge, University of Hawaii, or MARGE project) creating a machine that is basically integrated by modules that can be acquired all together or gradually giving the opportunity of future expansions of the installations in the operation rooms.

The Master–slave architecture has been proven with great success in many products in order to make possible the tele-operation of MIS robots. At present there are brands that have their own Master console technology (like Davinci or Artemis), however, many are using standardized products that evolved in the arena of tele-controlled robots for the industry or Military application as are Phantom and Mosul technologies. This is a very important step toward the standardization of all the MIS technology. The same can be said of the MIS robots that are controlled with joysticks or keyboards attached to Microcomputers.

There are many robots at present that claim to be designed for solo surgery; however, this might be practiced by the surgeon working in the same operation room with the machine. A new generation of Solo surgery robots might also include the possibility to be tele-operated, and in that sense offer the possibility to perform surgery in very distant places where there is no presence of qualified specialized medical personnel, with the use of only one surgeon operating the master console at hundreds or thousands of kilometers distantly.

An alternative possibility might be to have MIS robots that can be operated from more than one control station, opening the possibility for the intervention of specialists that are located distantly, with respect to the place of the operation, and that can assist the surgeon in complications that emerge suddenly in complex procedures. (Blue Dragon)

Another important aspect is that present development to improve for future technology is the capacity to block or lock the position of the robot at certain moment of the operation or the flow of commands on it. Also it is desirable to constrain the motions of the robot not only to its natural working space but to the region of the body that requires the intervention. This is extremely important to provide a well bounded working area, or when the surgeon must pause the procedure either to get better feedback, to attend an emergent situation or to redefine the strategy followed in the presence of complications. (Acrobot, Mako Surgical, Robodoc, Mars, Davinci).

To deal with undesirable configurations on robotic arms is also a very important aspect to avoid and to manage long operations. Therefore, systems that control the trajectory of the MIS robots in order to prevent singularities are being tested at present to be part of new generations of these machines. (Cardioarm, Evolap, Kalar, Robodoc, MC2E) (Figure 15).

Also the possibility of any risk associated with a power off or an unexpected shutdown or reset of the Computing guiding system in the middle of a surgery must be prevented, even in the presence of emergency power supply plants, in order to avoid the risk that the arms of the robot can fall in the patient's body due to the effect of gravity or that dangerous collisions can occur in between the machine arms and the surgeon or assistants. (Black Falcon, Cardioarm, Davinci, Kalar, Mako Surgical).

CT scan and X rays equipment is being incorporated in some MIS robots as a very important feedback mechanism in machines that work extreme risk procedures, like the ones that attain to brain surgery or spine one, since any minimal deviation of the instrument, with respect to the bone into the nerves, can produce irreversible damages or even fatal consequences. It is strongly recommended that this becomes a standard in the future. (MARS and Renaissance) (Figure 16).

Another very important standard that might be adopted in MIS robotic systems is the Scara kinematics, due to offer the best fitting in between the human body cavities and the robot arm workspace, avoid the problems related to the effects of gravity, and allow a good control on singularities and its compatibility with Digital Data technology. (Robodoc).

Figure 14: Artemis device.

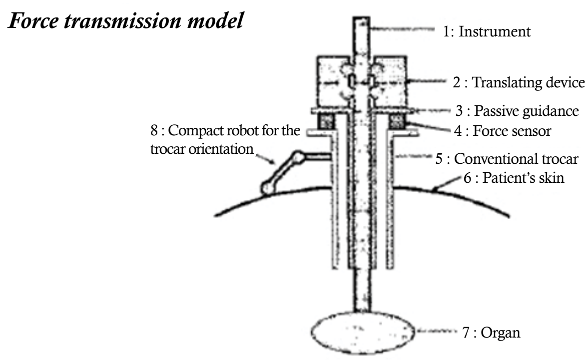

Figure 15: MC2E robot.

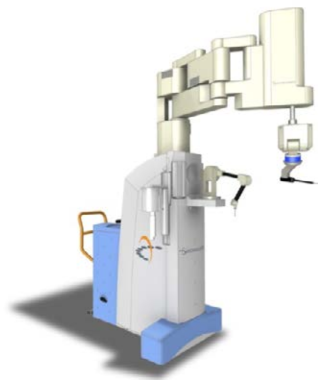

Figure 16: Robodoc surgery system.

Conclusions

Among the brands of MIS robots evaluated in the present study, the ones that offer similar or more degrees of freedom than a human hand are Active Trocar, Artemis, Mars, Mirosurge, Davinci, Mako surgical, Black falcon, Acrobot and Cardioarm. These robots therefore provide a good and precise replication of the motions that the Surgeon performs on the patient through the control unit and so reduces the margin of error in the procedures when they are performed distantly. Other kind of equipment evaluated in this comparative study, are exclusively recommendable for interventions performed with the surgeon in the site of the operation.

As the trends of specialization have evolved drastically on the market in the second decade of the XXI century on MIS robots, it is highly recommendable that the health center managers, who are in charge of the evaluation and ulterior acquisition of these equipment decide what are their priorities in to perform robotic surgery, this is in order to buy technology that really respond to the needs of the respective hospital or clinic, according to the segment of the patient population they work with and the nature of treatments they practice (Figure 17).

MIS robotic equipment that counts with touch, force and audio feedback are extremely valuable to improve the quality of the distant surgery on vital organs because it gives the physician a kind of feedback that prevents damage incurred while manipulating such delicate tissues, fineness unparalleled when uses cameras.

MIS robotic equipment that is intended to develop long distance surgery must have master slave architecture, with telecommunication technology included, and in that sense represents an absolute distinct technology than the one offered on mere surgery manipulators that can only offer a good framework to delimit the area of the surgery, to fix positions of tools, and offer a way to transfer motions without direct contact in between hands and tissues or a support for the hands of the surgeon to reduce fatigue (Figure 18).

An advantage when buying Medical robots that can be manipulated through a Universal Standard Master platform is that it is possible to integrate different brands on performed complex surgery procedures that demand diversity of tasks and tools. This gives more autonomy to the users of the machines with respect to the providers for future reengineering and adaptations of their installations in future uses of the surgery rooms, as well as offers an opportunity of greater customization into the design, planning and performing of surgeries (Figure 19).

It is crucial to identify, at the time of any acquisition of a MIS robot on evaluation, if it offers a passive support for performing a surgery transferring the forces that the hands of the surgeon can provide, or, if it actually contains some kind of electromechanical actuators that are able to generate forces and torques, or, if the equipment is designed for an interactive synergistic work with the surgeon, and finally if the machine has the ability to perform in a fully automated way procedures that are previously programmed by the physician. Each of these technologies are designed for different purposes.

Solo surgery is a goal that is desirable when the MIS robots are acquired to be used in health centers or hospitals where there is no availability of large surgery teams, as it happens in specialist clinics, or the ones in which surgeries might be performed not on a daily basis, but occasionally. At present the Brands that offer this possibility are Naviot, Viky, Robodoc, MC2E, Kalar, Heart lander Omni, flips endoarm and Davinci.

Compact MIS robots are ideal when the availability of physical space is too small to facilitate surgery rooms, as it happens in emergency health centers of factories, refineries, mines, power centrals. Davinci, Acrobot or Robodoc medical robots may be too large for such situations.

Force and motion scaling are essential ergonomic factors to consider in order to reduce the effect that fatigue can produce in the performance of surgery teams that work long hours. It is important

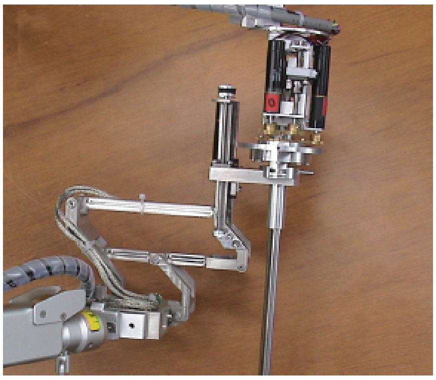

Figure 17: Active trocar robot.

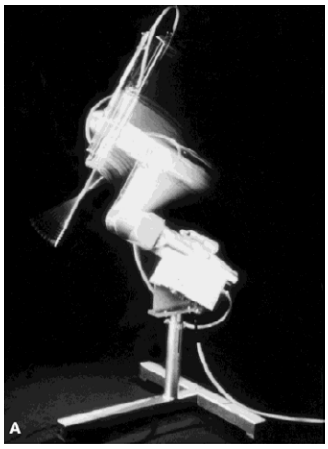

Figure 18: Artemis manipulator.

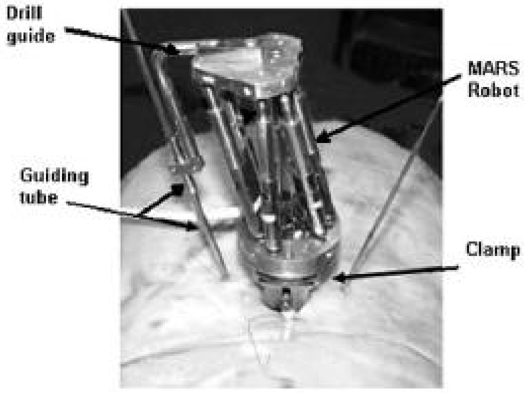

Figure 19: Mars spinal surgery robot.

to distinguish these human error preventive features from the ones developed for error correction purposes, like the Tilting and Tremor filtering. At present among the MIS robot that were evaluated in this study, only Davinci offers motion scaling as well as remor-tilting filtering, and Fips endoarm offers Tremor-Tilting filtering with Force Scaling, there are some other robots that offer just only one of these features.

On working in synergistic surgery, when the surgeon and the machine are playing different roles in the procedure, hands free command units (Foot pedal, Voice control, head movement Visual servoing) provide a very important feature to help in the distribution of tasks and reduce the stress on the surgeon because when using them, they can dedicate his hands exclusively to the performance of the procedure. Among the MIS robots evaluated in the present study it was found that the brands that offer this advantage are: Clem, Fips endoarm, Kalar, Naviot, Viky.

Modularity is a way to make the surgery robotic systems more accessible for many small clinics around the world. The idea is to offer to customers dedicated MIS robotic units for very specific tasks, the ones that can be bought separately and latterly integrated in ulterior stages for expansion of the surgery installations.

Standardization is a critical and very important step to follow if we want better robots, at lower cost and to extend the useful life of them. Developing clear quality standards that rule all the MIS sector of the industry could create possible bridges of compatibility among different products, making it easier for hospitals and clinics to gradually acquire the robotic equipment they need, as well as adapt or reengineer the ones they have for new uses.

A critical area of standardization in the current stage of evolution of the MIS robotic technology corresponds to the Master – slave architecture that has been proven with great success in many products in order to make possible the tele-operation of MIS robots using compatible control units.

-The use of this architecture is in great part responsible of the comparative advantage achieved by products like Active trocar, Blue dragon, Black Falcon, Evolap, Mars, Viky, Artemis, Davinci), Mirosurge , Orthodoc- Robodoc, kalar, Mako surgical (Figure 20).

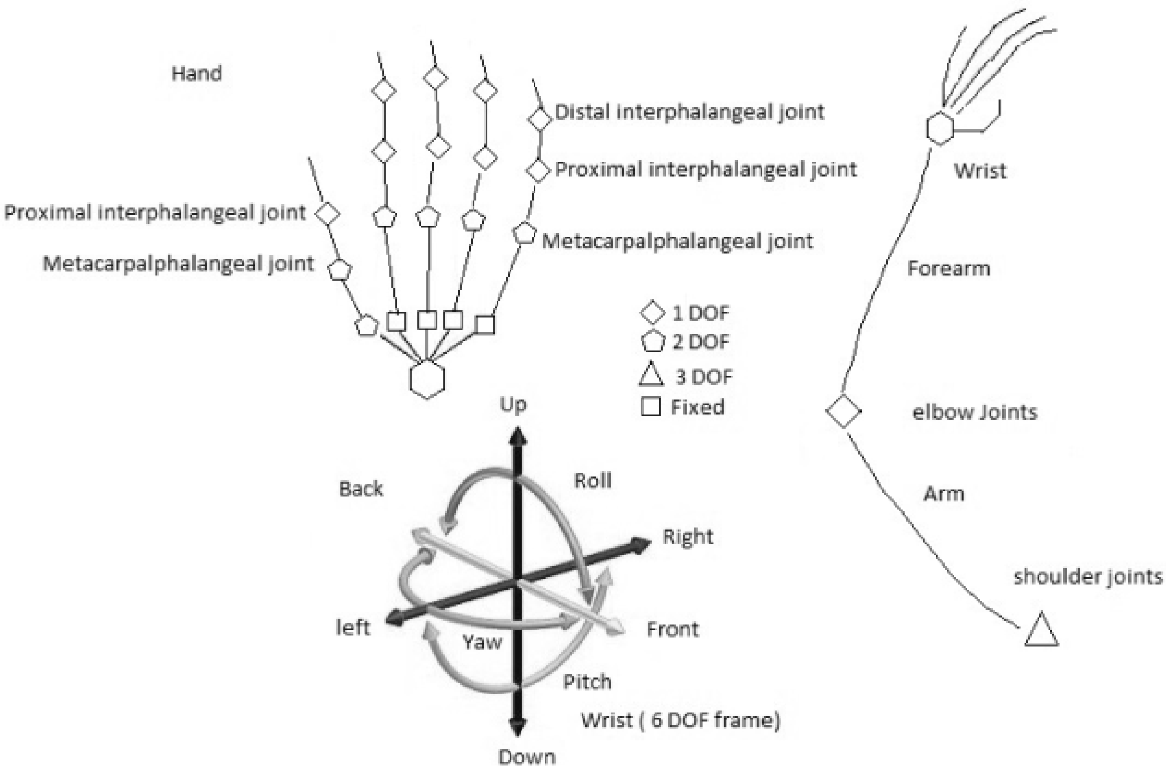

Figure 20: Degrees of freedom of human hand and arm.

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