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CONSIDERATIONS REGARDING THE APPLICATION OF PARALLEL ROBOTS IN THE SURGERY FIELD

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ABSTRACT
Robotic systems have been developed in every field where a further progress was constricted due to the human limitations in terms of speed, precision, fatigue, repeatability, strength, safety etc. The two major types of robots, the serial ones (anthropomorphic, open-architecture) and the parallel ones (closed-loop mechanisms) have divided their spectrum of dominance in different applications based on their specific advantages. One of the pioneer fields for robots is their assimilation in surgery, especially in minimally invasive procedures which aim the treatment of a disease with minimum damage to healthy tissue and suffering for the patient. The authors present in the paper a critical analysis regarding the characteristics of a surgical robot for minimally invasive surgery, making a comparison between the serial and parallel robotic structures focused on the customized demands of the Operating Room. In the final part of the paper the authors will present some surgical robotic models which are currently studied at the Technical University of Cluj-Napoca.
Keywords: parallel robots, minimally invasive surgery, competitive analysis, surgical robot

1. INTRODUCTION
The introduction of robots in the Operating Room has represented a two step process, conditioned by the progress in technology:

1. In the 80s the technique called "minimally invasive surgery" has been developed, when surgeons operated though small entry ports, using a video camera and small instruments in order to reduce to a minimum the damage of healthy tissue and the suffering of the patient;
2. In the late 90s the further progress in science, and above all the increased reliability of robotic systems, allowed companies to start the development of surgical robots which would assist the doctors in the operating room.

[1] presents the experimental comparison between the performance of a human assistant and a robotic one in manipulating a laparoscope. The results of this comparison emphasized the superiority of the robot in terms of motion steadiness. Several researchers invested efforts in assimilating the robot in the surgical arena [2]. Most of the robots, which assist the surgeons, are serial robots [2]. Nowadays there have been designed hybrid robots, which combine a first serial module with an open kinematic chain with a second parallel one having a closed kinematic chain. The serial module generates a large workspace while the parallel module is steadier and offers a high accuracy during the surgical operation. In this case, there are used force control algorithms in order to ensure the safety behavior and the accepted accuracy. The drawbacks of serial robots, determined by their structural construction, motivate the research in the field of robot assisted surgery for a continuous search of task oriented robot architectures that best fit a specific group of medical applications. As an alternative for the serial structure, the parallel one seems promising because of its advantages that fit medical applications. Therefore, some investigators focused on exploring the capabilities of parallel robots in medical applications [3].

AESOP [4] robotic arm, used to guide a tiny camera inside the body, was the first robotic system used in surgery dated from 1993. It was produced by Computer Motion, which developed several such versions of AESOP until they created Zeus^{TM} Robotic Surgical System with three robotic arms attached on the side of the operating table. A competitor of Computer Motion, Intuitive Surgical, designed another revolutionary system, da Vinci^{TM} Surgical System, which became the market competitor of Zeus until 2003 when the two companies merged. [4].

2. ADVANTAGES AND DRAWBACKS OF ROBOTIC SYSTEMS

Numerous studies have been conducted worldwide in order to analyze surgical robotic systems, to prove their advantages, to determine their limitations and to show one important thing: Robots will never replace the surgeons; they will just increase their capabilities beyond the natural human ones. Taylor has published in 1996 a study where he summarizes the highs and lows of humans and robots in surgery.

Table 1. Human versus Robot in Surgery [2]

Humans	Robots
Strengths Strong hand-eye coordination Dexterous (at human scale) Flexible and adaptable Can integrate extensive and diverse information Able to use qualitative information Good judgment Easy to instruct and debrief	**Strengths** Good geometric accuracy Stable and untiring Can be designed for a wide range of scales May be sterilized Resistant to radiation and infection Can use diverse sensors in control
Limitations Limited dexterity outside natural scale Prone to tremor and fatigue Limited geometric accuracy Limited ability to use quantitative information Large operating room space requirement Limited sterility and susceptible to radiation and infection	**Limitations** Poor judgment Limited dexterity and hand-eye coordination Limited to relatively simple procedures Expensive Technology in flux Difficult to construct and debug

As an obvious conclusion, in order to offer the best support for patients in the Operating Room, humans and robots must work together, the surgeon being the master (the decision maker) and the robot the slave – with excellent precision, untiring, without tremor and smaller than the human hand.

3. PARALLEL VERSUS SERIAL STRUCTURES IN ROBOTIC SURGERY

Starting from 2005, at the Technical University of Cluj-Napoca, within Simulation and Testing Center for Industrial Robots began a thorough study for the research and development of new robotic structures for surgery. This research is conducted in cooperation with the Surgery Clinic III of the Medicine and Pharmaceutical University of Cluj-Napoca, which have the first and most experienced laparoscopic surgery center in Romania [10].

There have been several aspects which encouraged the selection of abdominal surgery as the starting point in the national researches in the field of robotic surgery, such as:

The vast laparoscopic experience of the team of surgeons which can provide critical information with regard to the development of the robotic structure; the existence, on a global scale, of a single company which produces such robots; the prohibitive price of surgical robots; the low ergonomics – the surgeon requires a long period of training in order to be able to use such equipment; the large occupied volume in the operating room.

3.1. Critical analysis and best structure selection

The first interactions between engineers and surgeons aimed a clear and complete definition of the application from various points of view: workspace definition, mounting space, sterilization, safety, and ergonomics. As outcome, there have been issued 11 critical points which have to be fulfilled by a surgical robot which have been prioritized using the AHP prioritization matrix [9, 11] as shown in figure 1.

Table2. Technical characteristics of a surgical robot

Characteristics	
1.	High Accuracy
2.	Small Working Volume
3.	Speed And Force Control
4.	Haptic Feedback
5.	Fail Safe Systems
6.	Immune To Magnetic Interferences
7.	Avoidance Of Singularities
8.	Low Inertia
9.	Easy To Sterilize
10.	Compact Size And Low Weight
11.	Compact Arms

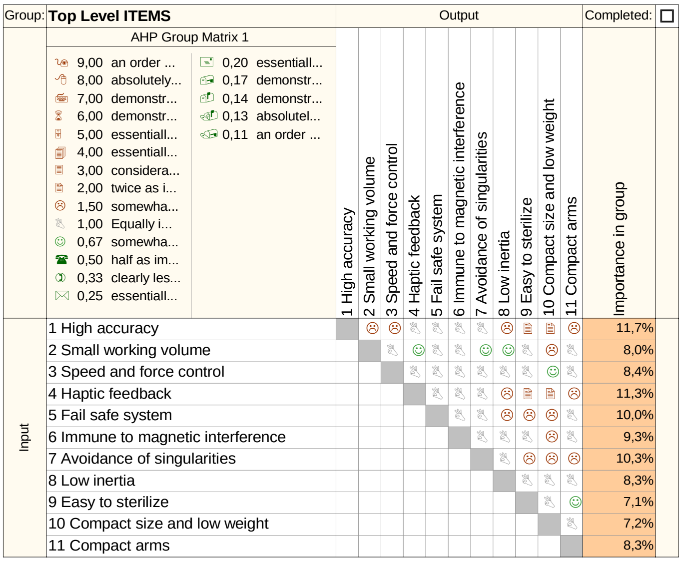

Fig.1. The AHP matrix

Once the requirements of the application are defined and prioritized, we need to determine the optimum structure of the robot. The selection will be carried out between the two known architectural types: the serial and parallel one.

The **serial structure** has an anthropomorphic architecture, resembling to the human arm, where the end-effector is connected to the base of the robot through a single open kinematic chain. Serial manipulators have large working spaces and a high dexterity but they have low precision and a very low ratio load / mass [6]. Furthermore, the errors are transmitted from a joint to the other so the end-effector has a cumulated error as the sum of all the joint errors. The **parallel structure** is characterised by a fixed platform connected to a mobile one through several independent kinematic chains. These structures have a small working space, but they have a high stiffness, are very precise and can develop very high speeds and accelerations.

In order to determine which structure would fit better the custom requirements of surgery the parallel and serial structures have been confronted with the specifications of the surgical tasks using the Pugh selection method, presented in figure 2 [9, 11].

The results favor the parallel structure which reports only one aspect inferior to the serial structure, the necessity of avoidance of singularity points.

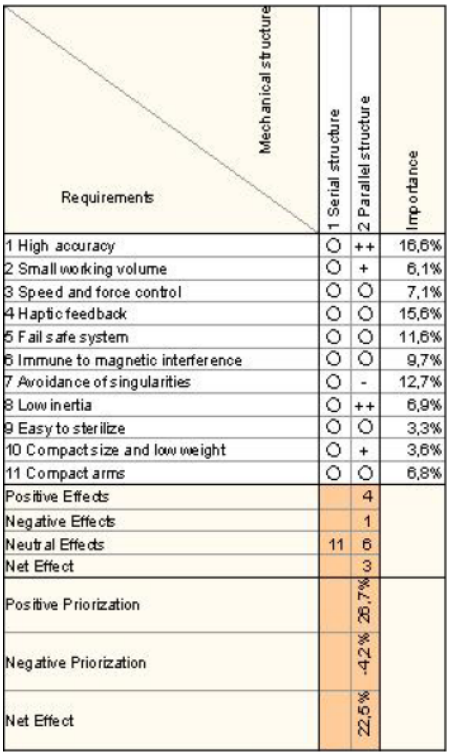

Fig 2. The Pugh selection method

Based on the criteria defined for the surgical system, the parallel structure has shown an overall performance with 22,5% higher than the serial structure.

One aspect that has to be pointed out is the workspace. In most applications the larger the workspace, the better. But in surgery, in case something goes wrong a larger workspace, means a larger volume that a robot out of control can cover, endangering the patient and the staff. The reliability of existing robotic systems is 98%, which means that there is still a 2% chance for something to go wrong, and in balance with a human life this percent is big.

Less moving components, better accuracy, higher stiffness, compactness, lower weight are all pointing towards the development of a robotic system which is based on parallel kinematics.

The first studies carried out at the Technical University of Cluj-Napoca, have generated several structural models [8] which are currently under further development (figures 3 and 4).

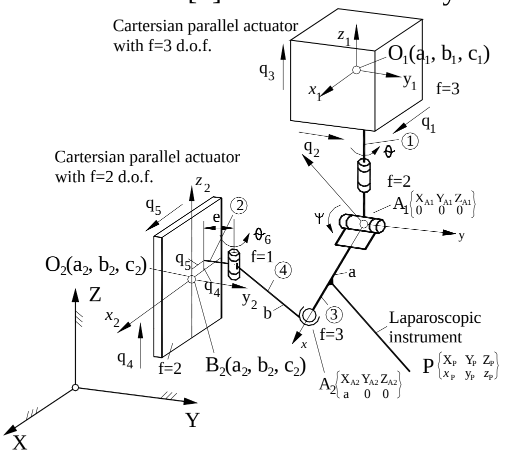

Fig.3. Parallel mechanism of F=0 family, with M=5 d.o.m (N=4, C_5=1, C_4=2, C_3=2)

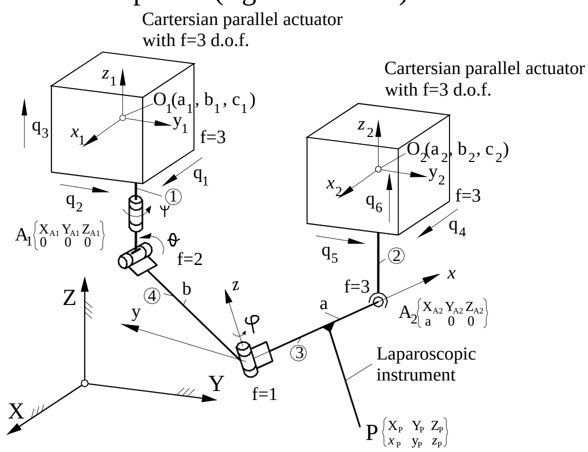

Fig.4. Parallel mechanism of F=0 family, with M=6 d.o.m. (N=4, C_5=1, C_4=1, C_3=1)

The symbols used in the figures, represent: M = mobility degree of the mechanism; F = mechanism family; N = number of mobile elements; C_i = number of "i" class joints [7], [8].

4. CONCLUSION

Robotic surgery is an on-growing field as several research institutes from all around the world struggle to find better solutions and develop more advanced systems. With this thorough analysis, of the requirements of the application, carried out together with a team of experienced surgeons, the team from the Technical University of Cluj-Napoca has done the first step towards the developments of surgical structures with a novel parallel architecture. Proving that parallel structures overcome the serial ones in the surgical field, and with a clear definition of the custom surgery specifications the team has meet all the prerequisites for the future development of innovative surgical robot structures.

5. ACKNOWLEDGEMENT
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