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Artificial Immunity Technique in Controlling Robotic Arm Applied in Knee Surgery

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Abstract: This paper present a new developed technique for robotic surgical model with high flexibility used in Total Knee Replacement (TKR) surgery. The proposed model used robot arm assisted technique to play the role of computer assisted surgery (CAS). Most famous type's orthopedic surgery equipments used navigation system. The system provide surgeon with extra support, as it help optimizing the implant's alignment according to structure of the body. The problem faces this types that the device has to be in fixed position during surgery, which limit the ability of the surgeon. Artificial Immunity System (AIS) technology is utilized to obtain two tasks. Processing Computer Tomography (CT) scan of the patient in order to be used by AIS considers the first task. In the second task AIS perform as controller to improve and adjust the movement of the robotic arm. The proposed technique is applied and tested for different cases. The proposed technique shows good results in performing TRK surgery.

Keywords: Total knee replacement surgery (TKR); Computer-Assisted Surgery (CAS); Artificial immunity System (AIS); Navigation system; Artificial Immunity System Pattern Recognition (AISPR).

I. INTRODUCTION

Minimally Invasive Surgery (MIS) is a new trend in medicine that aims at using robots to help surgeon in routine tasks. MIS focused on improved rehabilitation and pain management to accelerate post-surgery recovery. In early 2000 the field of general surgical interventions with the daVinci device was explored by surgeons at Ohio State University [1]-[2]. Total knee replacement (TKR) is type of surgery that used MIS concept.

TRK surgery is a common orthopedic procedure to replace damaged articular surfaces of the knee with prosthetic implants. To fit the prosthesis, each of the knee bones (tibia, femur and patella) should be cut to a specific shape to mate the mounting side of the corresponding prosthesis component. Joint replacement surgery with the aid of navigation system empowers surgeons to accurately fit new implant components specifically to the anatomy of the body, potentially provide the patient with: Fast recovery, extended life of implant, improvement in patient quality life and decreased the possibility of revision surgery. In 1985 a robot, the PUMA 560, was used to place a needle for a brain biopsy using CT guidance [3].

Through the years different models of robotics were developed and proved to be successful in surgery such as ROBODOC and CASPAR [4]-[5]. In this paper a new model that based on Robotic arm–assisted technique was introduced. The robotic arm helps control the depth, length and width burring with graphical feedback in the navigation system. Even though there are different types of models that appear every day, there are some problems that face surgeons [6]. Most types CAS equipment take a fixed position during surgery, also controlling the mechanical arm to move in free direction consider a challenge. Figure1 shows a sample of TKR mechanical arm.

Fig. 1. Mechanical arm of TRK surgery [3].

Today researches start looking forward to build a robotic model that can overcome all surfed problems. Artificial intelligent consider one of the ways to build a required control system. It started at ancient Egypt [7]. As time pass, new ways appear, trying to simulate natural systems, to approach solutions for existing problem one of these systems is immunity technique. In the mid 1986 the artificial immunity system stared with the farmer Packard and Perelson's. The first paper that has immunity on its title was published on 1994. It was published by Forrest et al and Kephart [8]. Immunity technique application has spread over and applied in different application.

Immunity technique has become accepted in the industry. In this paper, a control system is developed to adjust the output reached force of the robotic arm and a new approach is introduced to take the role of CAS navigation system and help surgeon align knee impact with computer imaging.

II. KNEE REPLACEMENT PROBLEM

In normal cases the mechanical axis of the leg starts from the center of the femoral head B, passing through the center of the knee joint O and ending at the center of the ankle C [9]. Figure 2.a shows That the angle θ between the normal mechanical axis OB and the axis of the femur canal OA is about 5o~ 9o [10]. When surgeon perform TRK surgery it's important to consider cutting five planes on the distal femur (plane 1-plane 5) and one plane on tibia (plane 6) in order to fit on prosthesis components. (Shown in fig.2.b) As a result, the precise measurement of the mechanical axis and the accurately milling of the fitting plane must be measured with high accuracy.

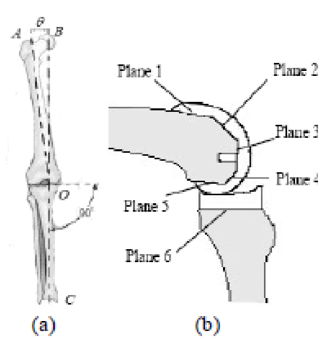

Fig. 2. Knee axis
(a) Normal Mechanical axis [9] (b) Surface of the bone [9]

III. ARTIFICIAL IMMUNITY SYSTEM

The vagueness and effectiveness of human brain challenged scientists through the years. During the fifties scientists started to simulate human brain to create artificial intelligent systems and used it in industrial applications. Most popular types are:

1-Genatic algorithm:

It successes in solve difficult expensive optimization problem. Although this system is great but as we see it does not solve a problem with different types [11].

2-Artificial neural network

It has shown to be successful for a wide variety of pattern recognition and control problems [12].

3-Artificial Immunity System:

The defense of human body one of the most amazing and mysterious phenomena, as the immunity of his body protect from any attack. The immune of human body has the ability to differentiate between antibody and antigen. In case of the system recognized antigen, it produces the appropriate an antibody [13]. Figure 3 illustrate simple construction of Immune system.

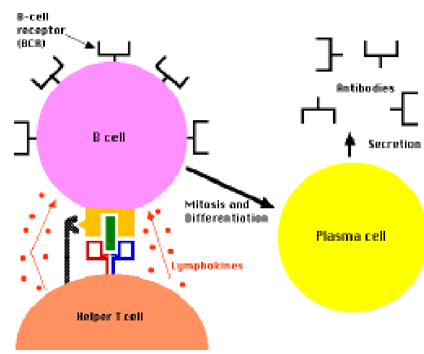

Fig. 3. Nature of immune system [14]

Immunologist Irun cohen defines three types of AIS scientists [4].

1- The *literal* school: Try to build systems that act as the actual immune of human body.

2- The *metaphorical* school: look for inspiration from the immune system.

3- People who aim to understand immunity through the development of computer and mathematical models.

In this paper the AIS is designed to perform two tasks.

3.1 Artificial Immunity System (AIS) Detector

The proposed model Tactile Guidance System (TGS) has 3 components: robotic arm, optical camera, and operator computer. CT scans are obtained for all patients. One-millimeter slices are take nat the knee joint and 5-mm slices are taken through the hip and ankle. Images are saved in DICOM (Digital Imaging and Communications).The pictures are then formatted and transferred to the software of the TGS to produce3-dimensional (3-D) models of each. Implant models are then positioned, (Figure 4)[3].

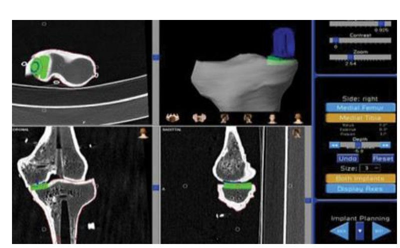

Fig. 4. TGS camera photo [6].

Artificial immunity system is programmed in operator computer to act as CAS. It compared CT images with the current status of the patient and predicts the appropriate location to cut before the navigation systems decide it. The proposed technique provides the surgeon with accurate results. More flexibility is offered to surgeon, as arm of robotics free to move instead of the fixed CAS.

3.2 Artificial Immunity system Pattern recognition (AISPR)

AISPR is designed to control the output force signal of the robotic arm. The control system depends on the force balance concept between the organ and the robotic arm.

Fig 5 shows the robotic arm used in surgical operation.

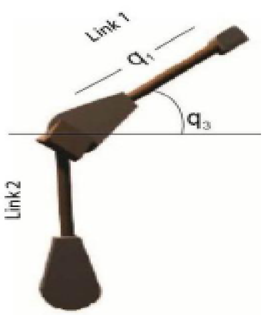

Fig. 5. robotic arm [15]

It consists of two links, a static link and a dynamic link. The junction between the two links has three degrees of freedom represented in the variable of motions *q1*, *q2*, and *q3*.The mathematical model of the dynamic link of the robotic arm is given by the following equations [10].

$$\ddot{q}_1 = \frac{1}{m}(u_1 \cos q_3^{\,2} + (u_2 - m\dot{q}_1\dot{q}_3)\cos q_3 \sin q_3 - \dot{q}_2\dot{q}_3 \sin q_3^2) \quad (1)$$

$$\ddot{q}_2 = \frac{1}{m}(u_2 \sin q_3^{\,2} + (u_1 + m\dot{q}_2\dot{q}_3)\cos q_3 \sin q_3 + \dot{q}_1\dot{q}_3 \cos q_3^2) \quad (2)$$

$$\ddot{q}_3 = \frac{u_3}{r} \quad (3)$$

Where

q1 :	Elongation of the arm
q2 :	Heading direction
q3 :	Angle with q2 plane
I :	Robotic arm inertia
m:	Mass
(u1,u2):	Forces along the (q1,q2)
u3 :	The torque about an axis through the contact point

AISPR used the output from AIS to determine the degree of motion for the arm to move.

IV. Simulation and Results

The research work is realized in form of three main stages, which are summarized in the following block diagram of Fig. 6.

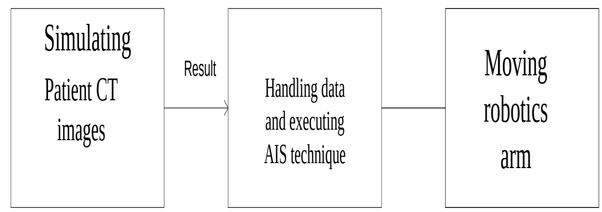

Fig. 6. Block diagram of developed work

The three stages are:

1-Simulating CT scanned data. Different cases for different patient are gathered to test the proposed technique.

2- AIS using the output data after being handled to accomplish the main target

3-Move the robotic arm using the output angle resulted from AIS.

The last mentioned steps are shown in details in the flow chart of Fig. 7.

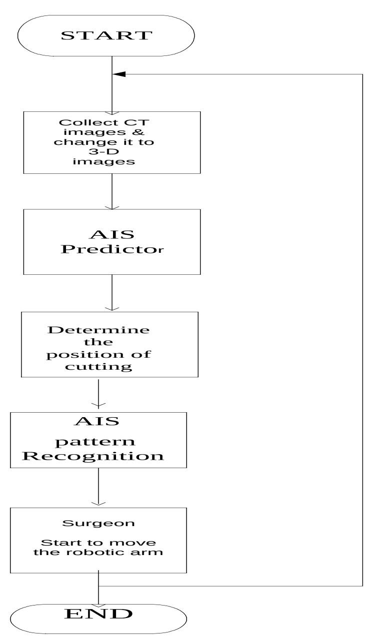

Fig. 7. flow chart of the system

The previous algorithm tested at different system condition. The new developed technique showed high flexibility and give efficient results. One of the cases was tested. As shown from fig 8 the output force for the organ with time isn't reached, some oscillations appeared and became greater with time (unstable case). Figure 9 clarified that the output force reaches the required reference signal.

As for *u*2, the immunity technique succeeded in recovering signal from rapidly changes (shown in figure 10,11). Finally fig 12 and 13 represents the output force response *u*3 in the absence of any controller and with AISPR controller. AISPR help *u*3 to reach acceptable smooth response.

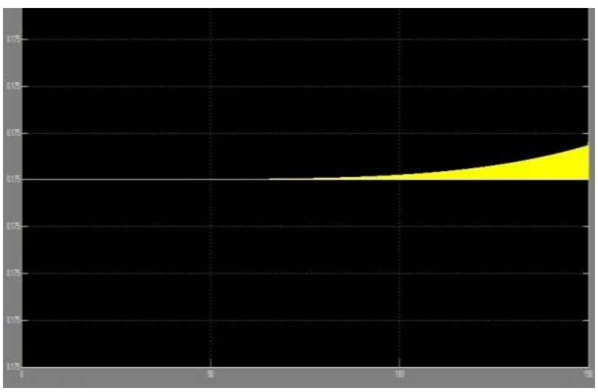

Fig.8. The force *u*1 versus time without applying AIS controller

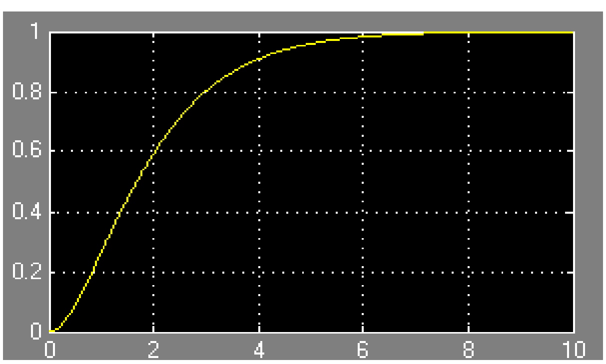

Fig.9. The force *u*1 versus time after applying AIS controller

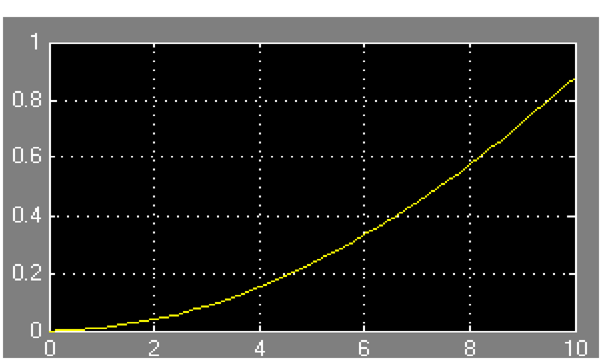

Fig. 10. The force *u*2 versus time without applying AIS controller

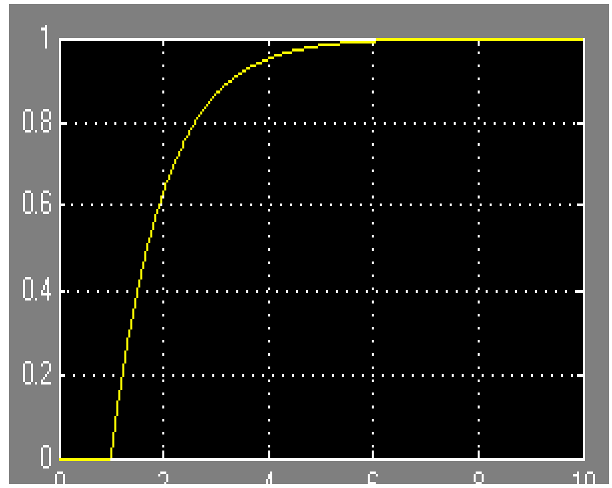

Fig. 11. The force *u*2 versus time after applying AIS controller

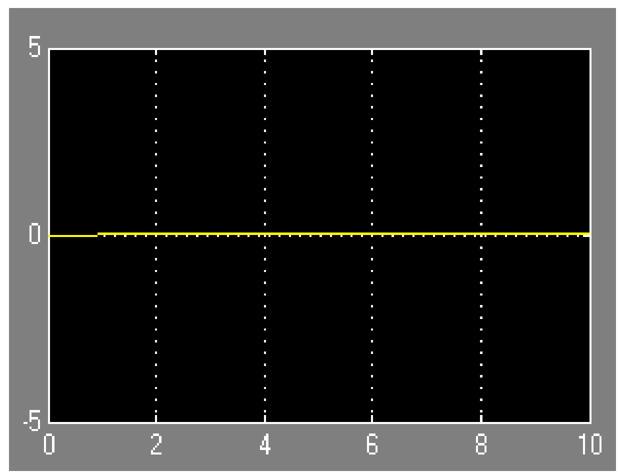

Fig. 12. The force *u*3 versus time without applying AIS controller

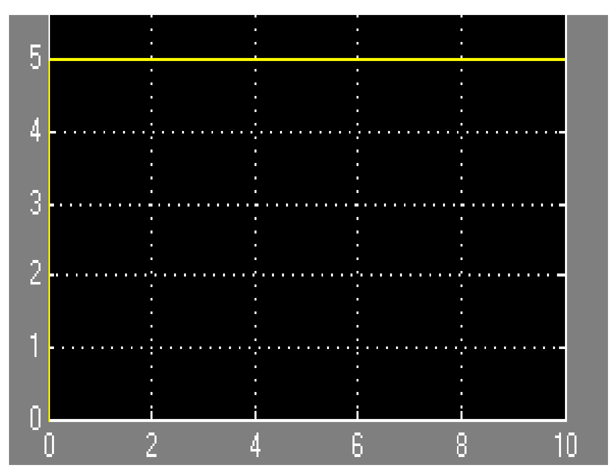

Fig. 13. The force *u*3 versus time after applying AIS controller

Another case was tested to insure accuracy of the proposed technique. Figure 14 shows that the organ force failed to reach the target, enormous oscillations appeared after a while (unstable case).

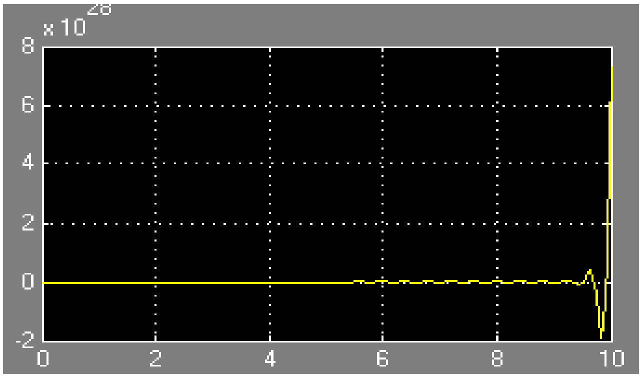

Fig. 14. The force *u*1versus time before applying AIS controller

After applying the proposed technique the system recover from oscillation and the output force reach the required signal (shown in Fig.15). Figure16 illustrate the behavior of force *u*2, the force test failed to reach the target. Artificial immunity technique succeeded in treating the oscillation (shown in Fig 17). Finally fig 18 represents the output force response *u*3 in the absence of any controller .Figure 19 shows that AISPR don't help *u*3 to reach acceptable smooth response.

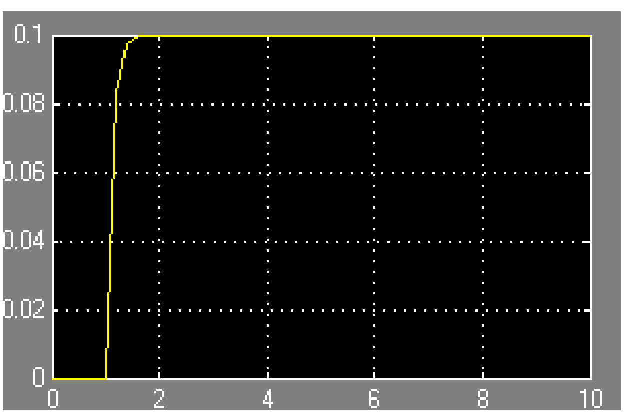

Fig. 15. The force *u*1versus time after applying AIS controller

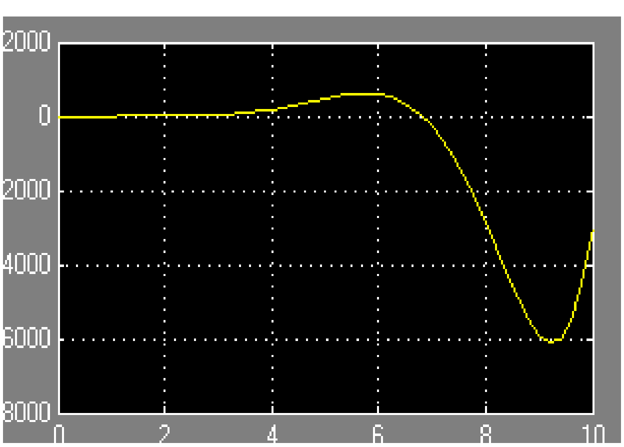

Fig. 16. The force *u*3 versus time without applying AIS controller

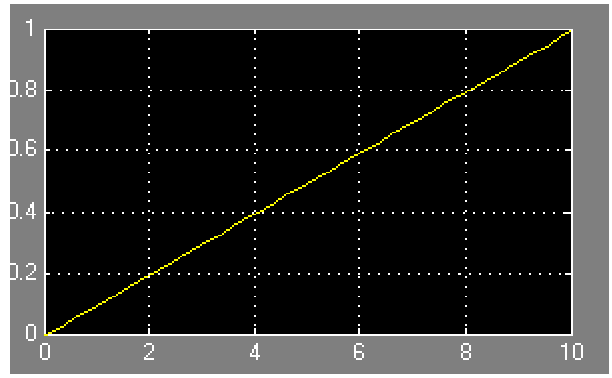

Fig. 17. The force *u*3 versus time after applying AIS controller

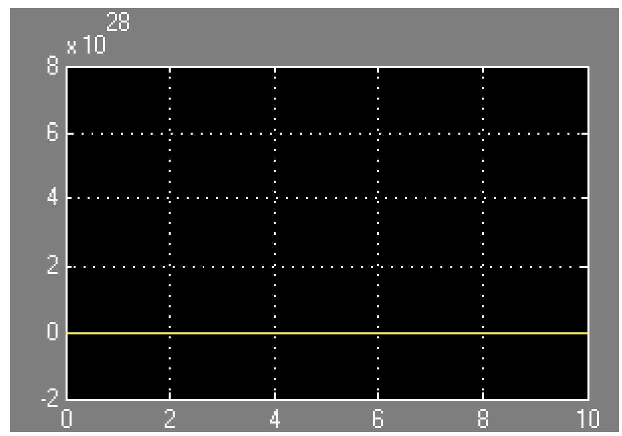

Fig. 18. The force *u*3 versus time without applying AIS controller

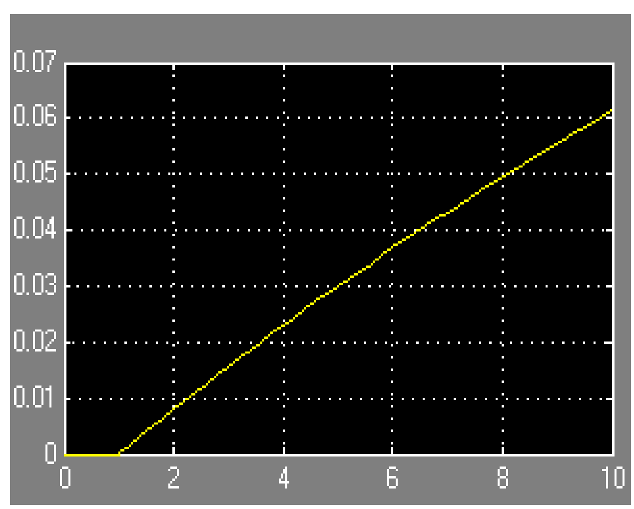

Fig.19. The force *u*3 versus time after applying AIS controller

V. CONCLUSION

A new robot assisted surgical model is proposed for TKR in this paper. Unlike existent solutions, this model is a surgical robot that combines together with a movable, navigation system build inside robotic arm. The navigation system is programmed inside the operator computer installed inside TGS.

Artificial Immunity System (AIS) is used to do the geometry and help surgeon to determine the exact location appropriate to cut and replace the knee. Robotics arm motion is also controlled using artificial system. The arm consists of two links. The three dimensions forces of the dynamic link are studied. The target is to produce a smooth and relatively slow force reaction from the robotic arm. The system is simulated and studied using different data of Knee surgery patients. Results show that in the absence of controller great oscillation and poor results are accomplished. Three controllers for the three dimension reference forces were added but the results of two dimension forces (u1, u2) continued having great oscillation and percentage of overshoot while the third (u3) converts to the anticipated outcome. After applying the proposed technique the results began to convert towards the required results.

REFERENCES

[1] McConnell, PI; Schneeberger, EW; Michler, RE (2003). "History and development of robotic cardiac surgery". Problems in General Surgery 20 (2): 20–30.

[2] Robotics: the Future of Minimally Invasive Heart Surgery. Biomed.brown.edu. Retrieved 29 November 2011.

[3] Kwoh, Y. S., Hou, J., Jonckheere, E. A. and Hayall, S. A robot with improved absolute positioning accuracy for CT guided stereotactic brain surgery. IEEE Trans. Biomed. Engng, February 1988, 35(2), 153–161.

[4] Taylor R. H., Paul H.A., Kazandzides P., Mittelstadt Hanson B. D.,W., Zuhars J. F.,Williamson B., Musits B. L., lassman E., and Bargar W. L.: An image-directed robotic system for precise orthopaedic surgery. IEEE Trans. Robot. Automat., vol. 10, pp. 261-275,Apr. 1994.

[5] Siebert W., Mai S., Kober R., Heeckt P.F.: Technique and first clinical results of robot-assisted total knee replacement. The Knee. 9(3): 173-180, 2002.

[6] Martin Roche, MD, Padhraig F. O'Loughlin, MD, Daniel Kendoff, MD, PhD, Volker Musahl, MD,and Andrew D. Pearle, MD: Robotic Arm–Assisted Unicompartmental Knee Arthroplasty: Preoperative Planning and Surgical Technique.The amirican journal of orthopedics. vol. 38, no2S, pp. 10-15, 2009.

[7] Kephart, J. O., "A biologically inspired immune system for computers", Proceedings of Artificial Life IV: The Fourth International Workshop on the Synthesis and Simulation of Living Systems, MIT Press, pp. 130–139, 1994.

[8] Andrew Watkins and Jon Timmis, "Artificial Immune Recognition System AIRS: An Immune-inspired Supervised Learning Algorithm", Journal, Genetic Programming and Evolvable Machines, Vol. 5, issue 3, September, 2004.

[9] Fanhuai Shi1, Jing Zhang1, Yuncai Liu1 and Zijian Zhao," A Hand-Eye Robotic Model for Total Knee Replacement Surgery", Proceedings of the 8th international conference on Medical image computing and computer-assisted intervention - Volume Part II Pages 122-130.

[10] Gray M. Ferguson, M.D., Richard J. Friedman, M.D. and FRCS(C): Foundation Knee System Primary Surgical Technique, Encore Orthopedics, Inc. 1999.

[11] Eiben, A. E. et al (1994). "Genetic algorithms with multi-parent recombination". PPSN III: Proceedings of the International Conference on Evolutionary Computation. The Third Conference on Parallel Problem Solving from Nature: 78–87.

[12] Packard and A. Perelson, "The Immune System, Adaptation, and Machine Learning", Physica D 22(1-3): 187-204, 1986.

[13] Marwa A. Abd El-Hamid, Noha H. El-Amary, Mohamed M. Mansour, "MICRO GRID STUDIES DUE TO FAULT OCCURRENCE USING IMMUNITY TECHNIQUE ", proceeding of the 11th IASTED European Conference on Power and Energy Systems , Napoli, Italy , pp. 20-25, 2012.

[14] Internet website: http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/B/B_and_Tcells.html

[15] Gamal I. Selim, Noha H. El- Amary, and Dina M. Aboul Dahab: Force Signal Tuning for a Surgical Robotic Arm Using PID Controller. International Journal of Computer Theory and Engineering Vol. 4, No. 2, April 2012.

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