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ACCURACY IMPROVEMENT BY NEW SENSOR SYSTEM FOR AUTOMATIC BONE DRILLING IN THE ORTHOPEDIC SURGERY

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Many orthopaedic operations involve drilling before the insertion of implants into the bones. Usually drilling is executed manually, which may cause some problems. In free hand performance of drilling some errors such as an inaccurate penetration and dilate of bone hole, overheating, harm soft tissues could be occurring. Automatic drilling is recommended to avoid such problems and reduce the subjective factor. The aim of this paper is to select, develop and test a new sensor system for a bone drilling robotized system. More in particular we utilize a sensor to measure thrust force during the bone drilling manipulation execution. Therefore a force sensor is fixed to the drilling robotized system. Moreover, an experimental identification of the drilling technical parameters such as bone resistant force and feed rates are done. The resistant forces are measured and plotted. The control algorithms and programs for drilling have done based on the experiments.

Keywords: Automatic bone drilling, sensor system, experiments, orthopedic surgery

1. INTRODUCTION

In the orthopaedic surgery many interventions involved freehand bone drilling procedures. Total knee (TKR) and hip (THR) replacement are ones of the most frequent performed orthopaedic operations [1-5]. In the both operations surgeons have to perform drilling manipulations in order to insert implant components into bones. Late detection of bone/soft tissue breakthroughs can cause unnecessary damage to the patient [1-12]. In manual operations, breakthrough detection is based on surgery's skills and visual inspections of the drill tip using imagining devices like x-rays [1-4, 6, 8-10, 12]. However, frequently exposes of x-rays is not useful for both surgeon and patient [1-4, 6]. The breakthrough detection based on thrust force measurement on the drill bit could be reduced or eliminated the need of x-ray imaging [1, 3, 6, 8, 9]. The successful execution of bone drilling requires a high level of precision, dexterity and experience [1-10, 12-15] because the drilling resistance is large and sometimes vibrates violently to difficultly grasp the hand-piece or even break the slender drill. Relatively large forces experienced during bone drilling pose significant challenges to effective application of bone drilling [7-15]. Drill bit breakage occurs frequently, and since the broken drill could obstruct placement of other devices and cause adverse histological effects due to corrosive reactions with the surrounding soft tissue, commonly necessitates follow-on procedures for removal of the broken drill bit [6, 8-11]. Generally, the increased torque during drilling induces shear stresses that exceed the strength of the drill bit, causing it to fracture [8, 11]. Similarly, uncontrolled or unpredictable bone drilling forces may result in drill breakthrough, causing considerable damage to surrounding tissue [4, 6-13]. Furthermore, drilling forces are the main source of heat generation during bone drilling [3, 4, 11-13]. Increased temperatures on the bone could induce thermo necrosis, and therefore, significant trauma to the bone tissue [2-4, 10-13].

The results show the automatized bone drilling manipulators or robots improve the quality of the drilling procedures [1-6, 10, 12, 13]. Moreover, the utilizing of the mechatronic drilling tools and robots will reduce/eliminate the need for X-rays imaging used in traditional bone fixation [4-8, 10, 12, 13]. In addition, there are several studies which refer to measurement of thrust force, feed rate, and detected breakthrough [1, 4, 6-8, 11-15]. It is will know that computer assisted surgery (CAS) and robots extremely decrease errors and time for orthopaedic surgery operations [1-5]. Usually, orthopaedic robot-assisted drilling systems consist of two modules first-one is executive drilling module and second one is assistant robot (manipulator) [1-3]. These days CAS robotized systems like Da Vinci and The RIO Robotic Arm of MAKO have been installed in many hospitals and performed many operations successfully [1, 2]. Unlike of big and expensive robots with high degree of freedom (DOF) and master slave systems [1-3], a small sizes, cost effective with special purpose robots and intelligent tools have been developing most recently [1, 2, 5, 15]. A miniature orthopaedic robot MARS with parallel structure is developed [1, 2, 5]. Praxiteles is a bone mounted guide positioning robot for TKA operation [4]. In order to remove the subjective factor and avoid the problems in hand bone drilling manipulations, the robot DORO (Drilling Orthopaedic RObot) has been created [11- 13]. Orthopaedic Drilling Robot (ODRO) has been developed latter [14-16]. This robot is intended to increase the patients safety in view point of it is accuracy, performance and sterilization. At the same time it has to be affordable for hospitals (low cost) and user friendly. ODRO can monitor time, linear velocity, angular velocity, resistant force, depth of penetration and temperature during the drilling process as well as bone breakthrough [11-13]. ODRO has own control/power block meets medical requirements. The aim of the present study is to select, develop and test a new sensor system for a bone drilling robotized system in order to increase accuracy and develop the control algorithms of it. First a small-sized compression load cell is selected to measure the thrust force in bone drilling procedure. Second we have designed a box to attach the load cell into a bone drilling robotized module. Third experiments on a pork bones are made to measure thrust force.

2. AN AUTOMATIC BONE DRILLING SYSTEM

During orthopedic surgery, a primary concern is to penetrate the bone tissue without causing mechanical and thermal damage. Therefore, without careful attention to the thermal and mechanical issues, bone drilling could impart considerable damage to the musculoskeletal system, reducing effectiveness of the surgical operation and increasing the post-operation recovery time. We are working on development of a hand-held robotized system for bone drilling procedures (Fig.1) to avoid the mentioned above problems. It is intended to perform drilling with preliminary setting of depth and stop automatically after the cutting process is completed. Drilling conditions would be changed automatically in accordance with bone density.

Fig. 1. A bone drilling experimental set up.

On the Fig. 2a are shown the executive drilling module and the control system of the experimental set up. In order to decrease length and increase of working zone of the executive drilling module we suggest the axis of motors to be parallel [17], unlike of these of DORO [12, 13] and ODRO [14-16]. Regards to the parallel structure the working zone becomes 121 mm, the length becomes 220 mm and height becomes 110 mm. The developed bone drilling experimental set up has the following basic components:

- Brushless DC motor MAXON [18]. The motor is equipped by servo controller/driver 1-Q-CE and amplifier DEC 50-5 [19].
- Linear motor 43000-17 [20]. It is a stepper motor with embedded screw for linear motion.
- Small and lightweight LMB-A force sensor (Fig.2.b) to measure thrust force [21].
- PCD-300 Series Sensor Interfaces [22].

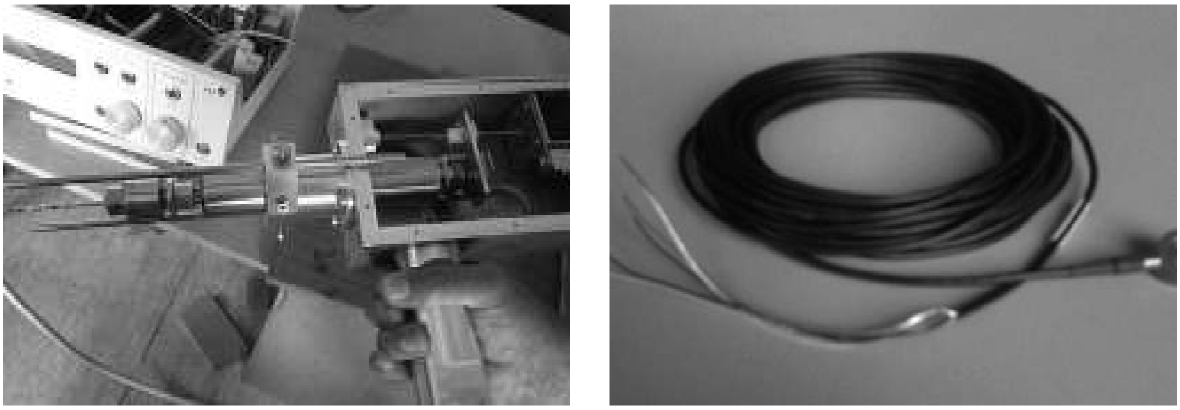

Fig. 2. The experimental bone drilling set up (a). The Kyowa's force sensor LMB-A (b).

In order to increase the accuracy of the bone drilling set up based on the experiments, date of literature, and companies' catalogues we have selected a force sensor LMB-A made by Kyowa (Fig.2b) to measure thrust force. It is a compact, lightweight, and low price load cell [21]. Moreover, to measure the thrust force more precisely during the drilling procedure execution the force sensor LMB-A is connected to the Kyowa's sensor interface PCD-300 series [22]. It is shown on the Fig.1. on the middle. The sensor interface PCD-300 series is a measuring instrument that can easily carry out measurements simply by connecting to a PC using a USB interface. We have designed and manufactured a box (Fig.2.a red arrow) for the LMB-A cell load in order to attach it to the moving part of the experimental drilling set up.

Control system of the experimental set up gives information about the drilling process execution in real time, for successful end of the task. The control block has terminals for connection with PC. They give a possibility to re-program the software, which is recorded in the controllers. Controllers can change and update the programs and to transfer the information between the sensors and PC while the drilling is executed in real time.

3. EXPERIMENTS

Bone is an in homogenous and anisotropic material, consisting two different types of bones: cortical and cancellous bone respectively. These two types of bone tissue differ in density, or tightness of the packed tissue. In a long bone such as tibia or femur, the outer shell is the cortical bone, and the inner layer is cancellous bone. Cortical and cancellous bone comprise the diaphysis of long bones and the thin shell that surrounds the metaphyses. In addition, cancellous bone is the metaphyses and epiphyses. The outside of the bones consist of a layer of connective tissue called the periosteum. The interior part of the long bone is the medullary cavity with the inner core of the bone cavity being composed of yellow marrow in adults [1, 4, 11]. The inhomogeneous structure of human bone, including a cortical (dense) portion at the outer part, followed by a cancellous (highly porous) portion and bone marrow, brings considerable complexities to application of bone drilling. The structure of bone varies between different bones (e g., femur vs. vertebra), between person to person, and between different age groups [6, 8, 11].

3.1. BONE DRILLING EXPERIMENTS. DETERMINATION OF THRUST FORCE IN DRILLING

The experiments were carried out under the following conditions: object of drilling - a pork bone; diameter of the orthopaedic drill - 4 mm; depth in bone drilling of tubular bones - 10 mm; depth of bone drilling in sponge-like bones - 20 mm; data reading - every 100 ms; velocity of drilling - 6 mm/s. Some of the obtained results are illustrated on the charts in Fig. 3 and Fig. 4.

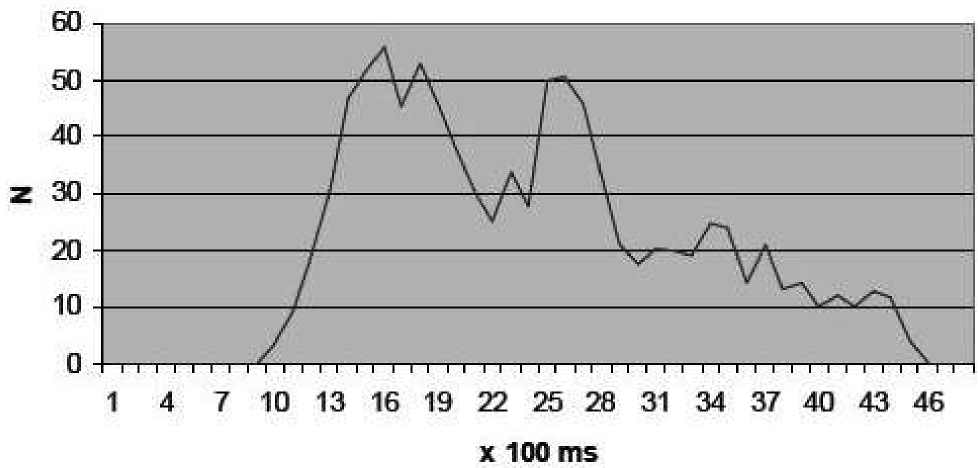

Fig. 3. Thrust force of drilling of cancellous bone.

It can be seen from the given results that in sponge-like bone drilling the resistance force varies within 30-55 N, while in tubular bone drilling the resistance force reaches up to 90-100 N, i.e. for one and the same bone depending on its structure the resistance force varies from 30 to 100 N. This means that during the performance of the operation the force of pressure should be consistent with the specific object and must be controlled accordingly.

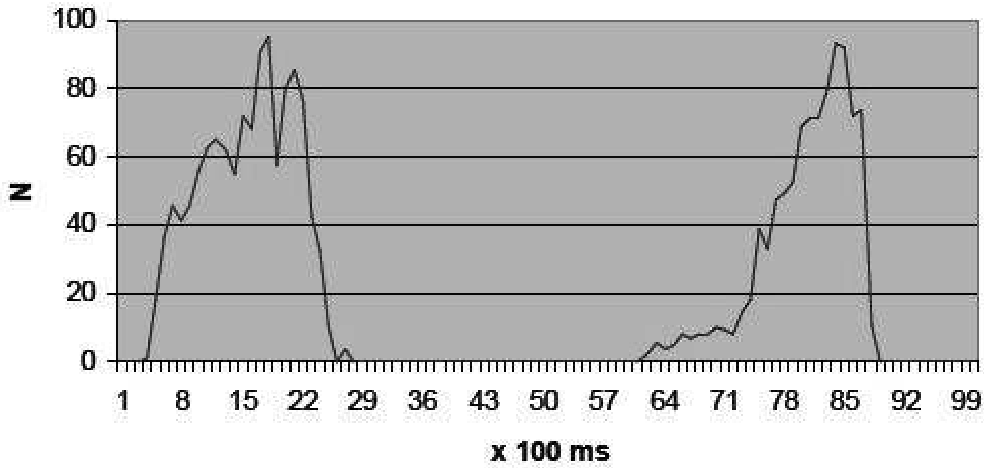

Fig. 4. Thrust force of drilling of cortical bone.

3.2. RESULTS

Specific drilling effects are revealed during the experiments. The thrust force is achieved by controlled automatic bone drilling regime in comparison with hand-drilling one. Comparison of new sensor system, implemented in the robot, with the old one is done and its better functional abilities are shown. Algorithms are created and their software realization is made. Curves of resistant force with respect of the time are presented.

4. CONCLUSIONS

Automatic bone drilling can solve the problems which arise during manual drilling. An experimental setup is designed to identify some parameters of bone drilling such as the resistant force due to variable bone density, the appropriate mechanical torque of drilling, the linear speed of the drill, and the electromechanical characteristics of motors, drives and corresponding controllers. The last leads to main conclusion that the automatic drilling guarantees higher safety for the patient. This will reduce/eliminate the need for X-rays imaging used in traditional bone fixation. The result has shown that, the bone drilling operation can be handled by a robot manipulator to improve the quality of the drilling operation. With this system, the bone breakthrough can be easily detected and further damage of the healthy patient tissue would be avoided.

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