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Review on Development of Bone Drilling System

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***Abstract*— For the individual not familiar with surgical instruments even a basic knowledge of the instruments and their uses may seem to be a challenging task. Most people have little experience with surgical instruments. The names are difficult; the differences may seem minuscule, and the uses for each instrument even more obscure. The beginner may easily feel intimidated without a proper introduction to the field. Bone is an anistropic material, the drilling of which is an essential part of internal fixation in orthopaedic and trauma surgery. Some research has been carried out into the drilling of bone, but there are no genitive recommendations available on the most suitable drill shape or on the optimum drilling speed that should be used in surgical practice. Electric or pneumatic drillers are necessary in orthopaedic surgeries requiring bone drilling, such as for screws, steel wires, and internal or external fixators insertion. Special medical/ surgical-use drills are fully dismountable and autoclavable, allowing for an appropriate internal and external parts cleaning after use and sterilization assurance. In the paper we have reviewed about different types of orthopedic drilling system, such as hand-held system, image-directed (CT image) based system, temperature based system, automatic systems.**

***Index Terms*— orthopedic surgery, bone-drilling machine, hand-held drilling system, image-directed, temperature, automatic, break-through detection.**

I. INTRODUCTION

Bone fracture is common in day to day life. Fractured bones are capable of healing itself naturally by generating new bone forming cells and blood vessels at the fracture site. Therefore restoring of the fractured parts to their initial position and maintaining them there until the bone heals is crucial. This is done either by setting and immobilization of fractured part from outside (conventional approach) or internal fixation of fractures using immobilization screws, wires and plates (direct approach).The limitation of the conventional approach lies in the fact that the parts cannot be optimally aligned. In some cases the fracture alignment from outside is not possible also the healing takes a long time. These limitations are overcome by direct approach in which drilling is a common operation for internal fixation of bone fracture by screws or for prosthetic device installation [6].

Orthopedic surgery involves the use of motor-driven tools held by the surgeon, such as drills and saws. The use of drilling in orthopedics is required in about 95% of post trauma treatments (such as traction) and interventions. Holes in bones are produced for the following reasons:

- mounting screws for anchor plates or exoskeleton devices for the fixation of fractured bones;
- mounting screws for traction equipment.

An analysis aimed at assessing the size of the potential market of new drilling tools in orthopedics has been performed. The number of potential users in Europe is about 3000 (i.e., hospitals potentially interested in the results of the project). In 1992, the total number of interventions executed in Italian public hospitals was 388578 and 62783 in conventional private hospitals operating with the National Health Service. The magnitude of the potential market justified the development of a new drilling tool aimed at improving the overall quality of surgical interventions via the reduction of invasiveness of drilling procedures. Drilling in the osteosynthesis of long bones (DOLB), such as femur or tibia, has been chosen as A procedure for focused study, but the authors are confident that the results of the study would be immediately useful for other procedures involving drilling [1].

Many problems are encountered when drilling bone in orthopaedic and trauma surgery such as hole accuracy, drill wander (walking) and heat generation. Also, other unpredictable situations can occur due to the non-homogeneous structure of the bone material itself. Many different drill-bit designs and geometries have been suggested over the years, each with its own claim to success but most of them are based on conventional twist drill geometry for the drilling of metals. The drills used are: twist drills, guide wires and large diameter drills/reamers [3].

II. LITERATURE REVIEW

1. Hand-held drilling system:

The mechatronic drill system (schematically depicted in` Fig. 1.1) consists of the following basic components: the drill unit, the electronic power controller, the computer, and the pedal switch. The whole system is controlled by real-time control software running on the PC, the inputs of which arethe following:
• the force applied to the drill bit, measured in the range 0–60 N;
• the pedal state changes;

• the hole-type setup.

The outputs generated are as follows:
• the feed speed, typically varying between 0–2 mm/s;
• the feed position in a range between 0 (before drilling)–60mm (maximum penetration).
The system high-level control loop is an autonomous thread of the real-time software controller; it is executed on the main CPU (an Intel Pentium) of the PC and runs at 50 Hz. The two low-level control loops, one for the feed servo and the second for controlling the chuck angular velocity, are executed directly on the digital signal processor (DSP) motion controller board at approximately a 2-kHz rate [1].

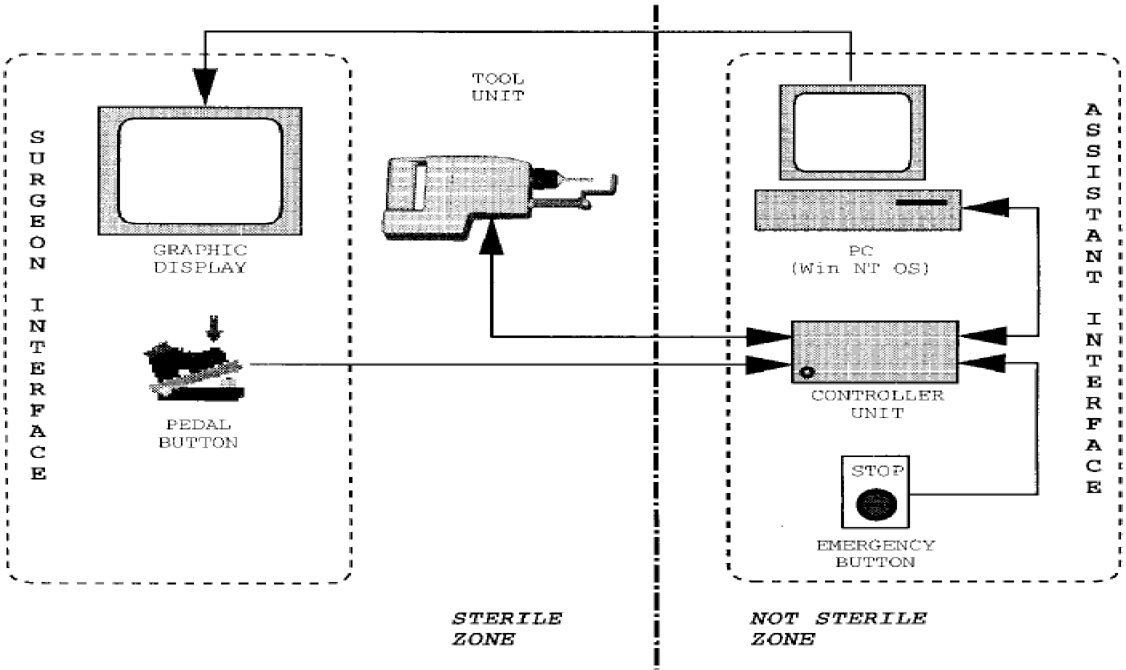

Fig. 2.1.1 Block diagram of hand-held drilling system [1]

2. IMAGE DIRECTED (CT IMAGE) BASED SYSTEM:

Before surgery, three titanium pins are implanted through small skin incisions into the greater trochanter and condyles of the patient's femur. **A** CT scan is made of the leg. The presurgical planning system automatically locates the pins relative to the coordinate system of the CT images. The surgeon interactively selects an implant model and determines its desired placement relative to CT coordinates. This information is written to a diskette for use in surgery. Key steps of the intraoperative procedure are shown in Fig.1.2 for an *in vitro* test on a cadaver femur. The operating room scene during the first canine clinical trial in May, 1990. Briefly, the procedure is as follows.

1) The robot is brought into the operating room and powered up. A sterile cutting tool is attached to a tool interface just below the force sensor, and the robot is covered with a sterile drape. The patient data diskette is loaded into the robot controller, and the robot is placed in a standby mode.

2) The patient is prepared and draped in the normal manner. Surgery proceeds normally until the acetabular component of the implant is implanted and the ball of the femur is removed.

3) The robot is brought up to the operating table, and the femur is rigidly attached to the robot base, using a specially designed fixator. The three titanium pins are exposed manually.

4) A ball probe "cutter bit" is inserted into the collet of the cutting tool. The top center of each pin is then located by a combination of manual guiding and autonomous tactile search by the robot. Although several modes of manual guiding are available, the most commonly used is force compliance. The surgeon simply pulls on the shaft of the cutter; the robot controller senses the forces exerted on the tool and moves the robot in the indicated direction.

5) The robot controller uses the pin location information to compute an appropriate transformation from CT coordinates to robot coordinates. The ball probe is replaced by a standard cutting bit, and the robot cuts out the desired implant shape at the planned position and orientation relative to the pins. The surgeon monitors progress both by direct observation of the robot and patient and by looking at a graphical display depicting successive cuts.

6) When cutting is complete, the femur is unclamped from the fixator, and the robot is moved out of the way. The rest of the procedure proceeds in the normal way, with the added step of removing the locator pins from the patient [2].

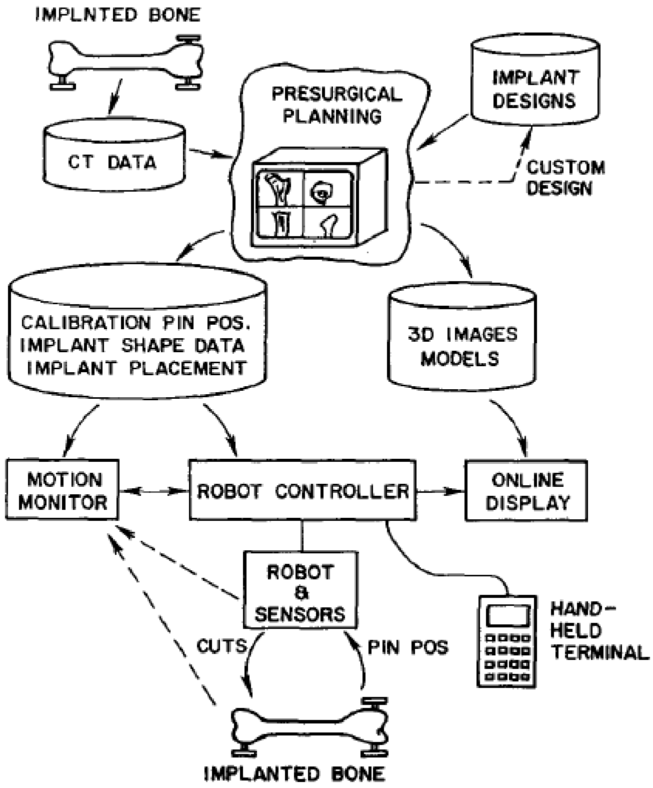

Fig. 2.2.1 Architecture of image directed drilling system [2]

3. TEMPERATURE BASED DRILLING SYSTEM:

The most efficient method of measuring the temperature at the cutting edge was to locate a thermocouple as close as possible to the point within the drill-bit itself. The reasoning for this was that stainless steel is a much better conductor of heat than bone, having a thermal conductivity of 14 J/msK, and it was considered that better results could be obtained than those previously available.

3.1. Drill-bit design

In order to place the thermocouple in the drill-bit as close as possible to its cutting edge, surgical stainless steel piping of 4.5 mm outside diameter having a bore of approximately 1 mm was selected to make five separate drill-bits. This steel tube was ground to a diameter of 3.2 mm and fluted to a helix angle of 23 degree, as for normal twist drill manufacture. The tip of each tube was closed by welding using a filler rod of the same stainless steel material. Three of the drill-bits were then ground to a 90 degree point angle and one each to 70 degree and 80 degree. A K-type insulated thermocouple was placed and `bedded' inside the drill and its leads were then glued along the drill barrel. The wall thickness at the cutting edge was in the region 0.5±0.7 mm. The system was calibrated by placing the drill-bit and a standard thermocouple into a container of water that was heated in steps of 5 K to boiling point. The temperature response time for the drill-bit compared to the thermocouple was, at most, 3 s throughout the range.

3.2. The drilling machine

The machine used for drilling was a modified Emco milling machine with an inverter fitted to the spindle motor, which gave a speed range from approximately 50±2500 rev/min. The spindle speed reading was detected by a specially fitted digital read-out meter that was ‘switched' by a small proximity magnet attached to the top of the spindle. A small drilling machine chuck was used for holding the drill-bit. The chuck in turn was rotated by the milling machine collet. The chuck also had a hole drilled through its shank to allow for the lead wires from the thermocouple to be threaded through it. These lead wires were then connected to an electrical ‘connector block,' the other side of which was connected to a pair of brass slip rings fitted at the top of the machine spindle. A pair of brushes was then used to make electrical contact with a digital read-out pyrometer capable of reading to ±0.1 K. An infinitely variable DC servo motor was connected to the feed lead-screw through a toothed belt and reduction gear for precisely controlling the feed rate from 1 to 200 mm/min.

3.3. The drilling dynamometer

All drilling took place by clamping the sample bone onto the work table of a sensitive drilling dynamometer that was capable of taking pieces of a length of up to 300 mm and height 25 mm. This dynamometer measured both the torque
and the thrust forces generated. The active elements of the measuring cantilevers were Kwoya KFD-2-D16-L30-type strain gauges with pre-attached lead wires in a half bridge circuit with separate identical compensation gauges. The dynamometer was calibrated by physically applying different known load and torque values. The general machine arrangement is shown in Fig. 2.3.1.

3.4. The drilling procedure

The thawed bones were clamped to the work table of the dynamometer and then drilled. At least two holes were drilled for each speed and feed. Occasionally, wedging of the drill-bit occurred due to the chips not clearing along the flutes. This happened particularly in the high speed drilling of bovine cortical bone. In one case this wedging resulted in the fracture of the drill-bit. Due to this, if there was any major variation from one piece of data to the next, the drill was changed and the experiment was repeated to verify the result. The speeds used were 400, 600, 800, 1000, 1200, 1400, 1600, 1800 and 2000 rev/min. These were chosen in order to go below and above the speeds recommended in the literature for the drilling of bone. The feeds ranged from 40 to 60 mm/min and generally settled at 50 mm/min. these feeds were chosen arbitrarily, since in orthopedic practice the feed rate varies from surgeon to surgeon and in the case of a particular surgeon there will also be a variation, since the drill is hand-held.

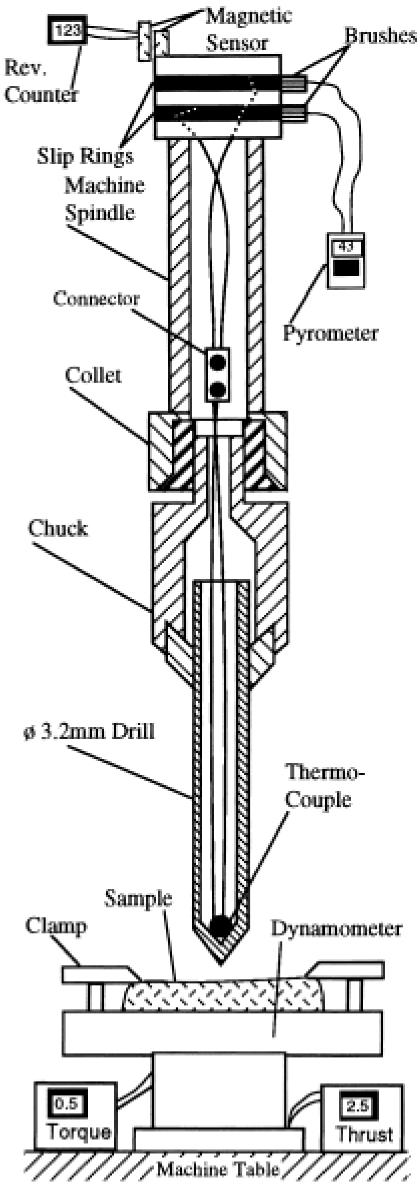

Fig. 2.3.1 Assembly of temperature based drilling system [3]

4. AUTOMATIC BONE DRILLING SYSTEM:

The experimental setup of the bone-drilling system is shown in Fig. 2.4.1, and it consists of a drill feed unit, a drilling module, a thrust-force sensor, and a drilling motor torque sensor, as well as a PC-based computer system.

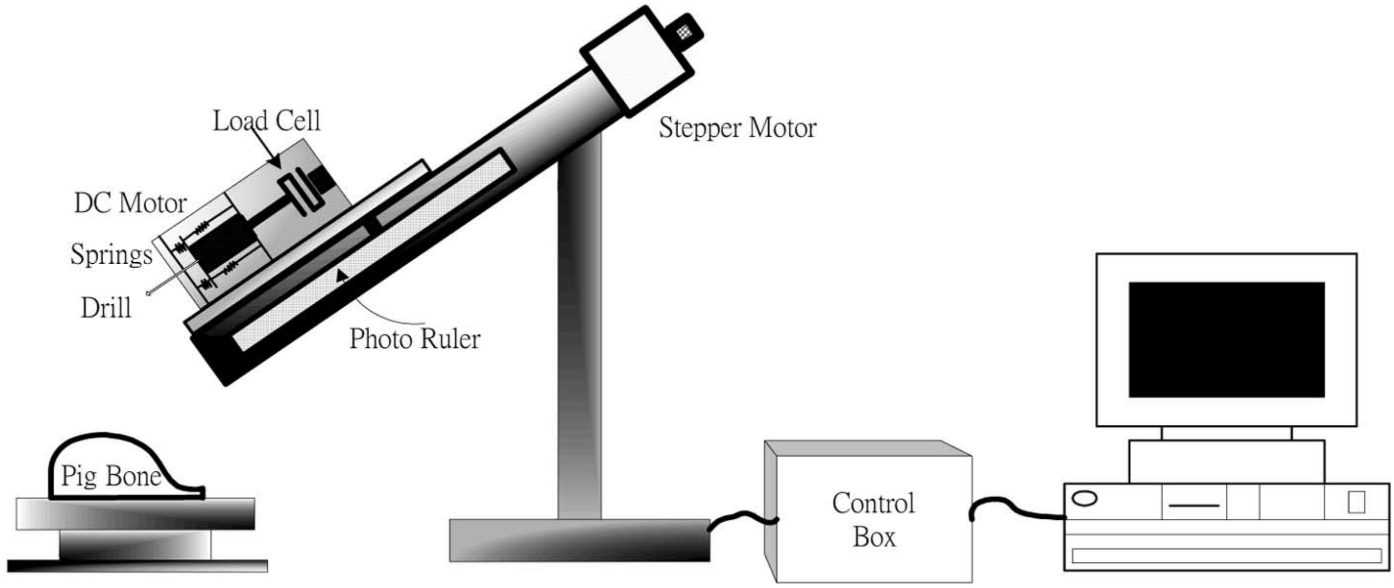

Fig. 2.4.1 Experimental setup of automatic drilling system [4]

The hardware block diagram of the bone-drilling system is shown in Fig. 2.4.2. The drill feed unit is driven by a stepper motor through a ball screw, and the stepper motor is driven by a micro-stepping driver with a resolution of 1600 steps/rev. The pitch of the ball screw is 5 mm and thus the resolution of the drill feed unit is 5 mm/1600 pulses. The digital differential analyzer (DDA) is a recursive technique for digital solutions of differential equations in real time. The DDA is used as a uniform pulse generator, sending equally-spaced pulses in N clocks (n<N). The drill feed displacement is measured by a photo ruler with a resolution of 1 mm per 1000 pulses, and the drilling thrust-force measurement is obtained from a load cell in which the voltage/force ratio is 0.102 V/N. A high-speed dc drilling motor is driven by a torque-mode driver, which is implemented by linear circuits. In order to eliminate noise, the measurements of the thrust force and drilling motor torque are filtered by software low-pass filters [4].

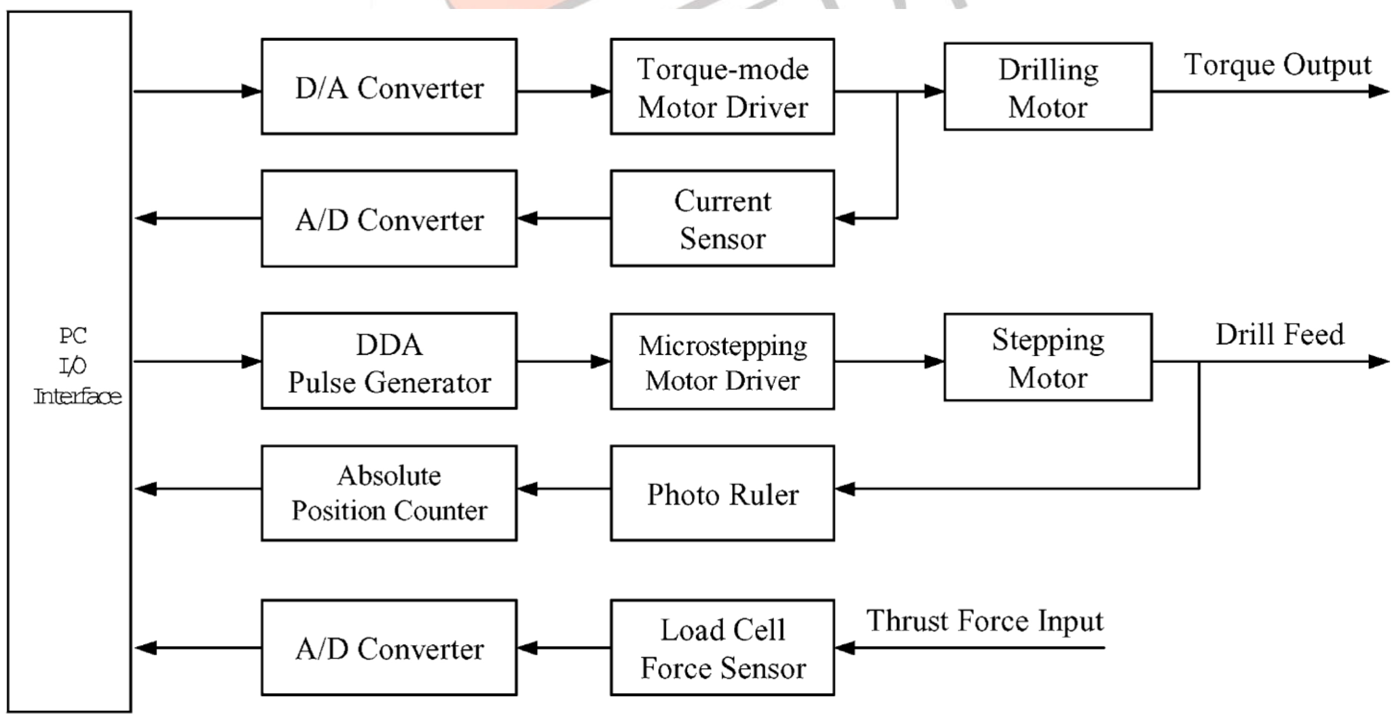

Fig. 2.4.2 Block diagram of drilling system [4]

5. FUZZY LOGIC BASED DRILLING SYSTEM:

This section will present the detection algorithm of high force during the drilling process. The detection algorithm in the Force Control subsystem is design based on conditionally executed system as in Figure 2.5.1. It is built with two Enabled Subsystems, a relational operator, a merge block, an output port and four input port signal together with a constant block from the Matlab Simulink library. It is implemented using WinCon software to generate a real-time code.

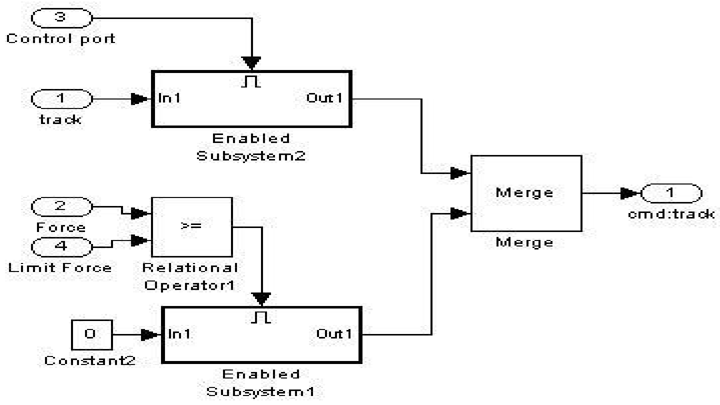

Fig. 2.5.1 Block diagram of detection system [5]

Figure 2.5.2 shows the process cycle for the drilling operation. It begins with the setting up of the drilling parameters: velocity (v), acceleration (a), cutting speed and the desired robot position (xd) in the track position. Then the operation mode needs to change during the drilling processes to activate the detection algorithm system. The drilling thrust forces are measured during the drilling processes where the measured forces are in the tri-axial direction denoted as Fx, Fy and Fz. Only force in the z direction (Fz) is used to compare with the value of the threshold force (Ft) in the algorithm. In Equation (1) the xn denotes the current position of the robot and xi is the initial position before the drilling processes.

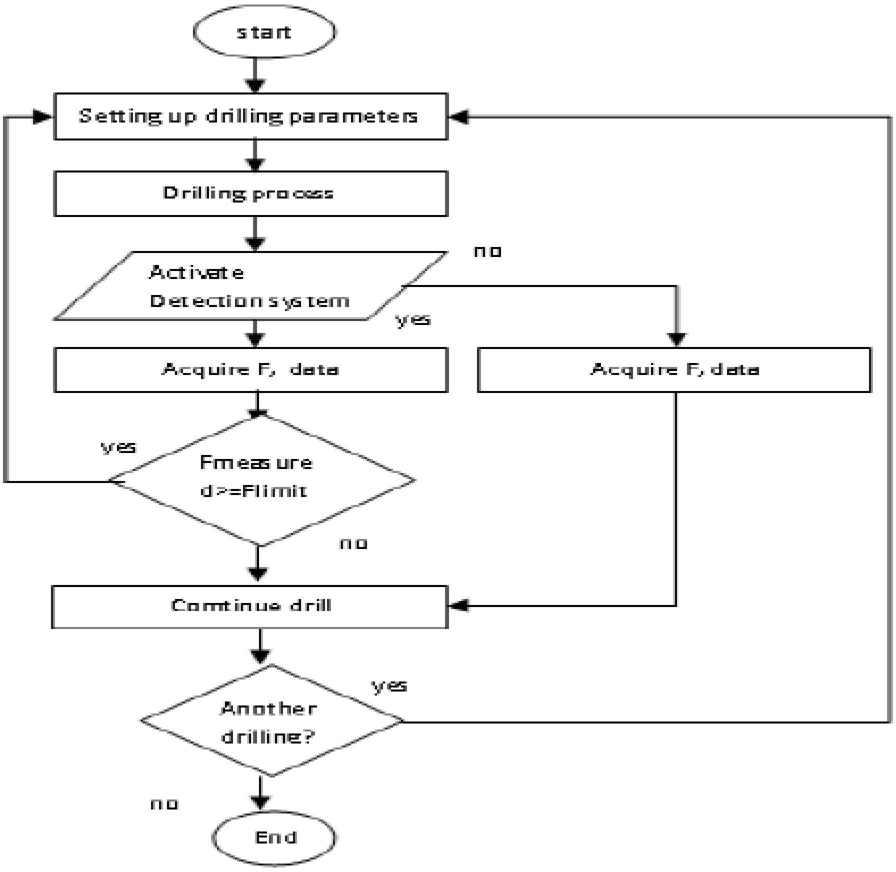

Fig. 2.5.2 Flow chart of detection system [5]

III. Conclusion

The conclusion of above review systems is shown in table 3.1.

Sr. No.	Title	Year	Conclusion
1.	Hand held drilling system	1997	The approach of this system is focus on-Effectiveness of penetration control, Friendliness, Patient safety, Medical staff safety, Modularity of control software based on fuzzy reasoning.
2.	An Image-Directed based drilling System	1994	This system developed an image-directed robotic system to augment the performance of human surgeons in precise bone machining procedures in orthopaedic surgery, initially targeted at cement less total hip replacement surgery. The total system consists of an interactive CT-based presurgical planning component and a surgical system consisting of a robot, redundant motion monitoring, and man-machine interface components
3.	Temperature based drilling system	1999	In this system the temperature increased as the depth of the hole increased. The temperature developed at the drill cutting edge, whilst high relative to previously suggested limits, does not in fact seriously damage the effective depth of bone thread used in securing surgical self-tapping screws.
4.	Automatic drilling machine	2004	This system attempts to solve the problem of bone drilling. The goal is to realize a control system that drills with a contact drilling force and can automatically stop drilling at the moment of

			breaking through. Moreover, breakthrough detection comes from to the threshold information of the thrust force as well as the trend of both the drilling torque and the feed rate.
5.	Fuzzy logic based drilling system	2012	The purpose of this study is to develop a force control algorithm that detects high force during bone drilling process where the drilling process will halt and return to a safe position when high thrust force detected. The algorithm is built using Simulink model under Matlab software. The control algorithm detects excessive force and calibrates the force in tri-axial direction as the threshold value.

Table 3.1 Conclusion of different Systems

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