Applying Enhanced Reality in Fracture Reduction with External Fixation

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Abstract: - The paper illustrates a technology under development at the Biomedical Laboratory of the Department of Mechanics of the University of Calabria, in cooperation with other centers, aimed, through the use of "Enhanced Reality", to the elimination of X ray exposure of Doctors and technicians, reducing it also to patients, during fracture reduction procedures. The term "Enhanced" is used instead of the more common "Virtual" since the system allows the relative position of the bone fragments to be measured, in order to compute and plot the actual position of the bones on a radiographic scale during the reduction process, and on two approximately perpendicular planes, even if this is not visible to the operators. The research is takes origin from two Italian patents and a PCT application, about to be released as European Patent.

Key-Words: - Fracture Reduction, Computer Aided Orthopaedic Surgery, Enhanced Reality in Surgery

1 Introduction

A person subjected to a radiological examination exposes himself to a potential somatic hazard and the future generation to a genetic one [1-5]. This drawback must be weighed against the clear diagnostic advantages the examination bears [6-9]. On the other hand, when fractured bones have lost their alignment, visualisation of the fracture is an absolute necessity.

The project motivation is hence clear, improving doctors' quality of life, enabling them to work in e safer environment. However, a clear advantage can be also obtained for the patient, with a greatly diminished amount of ionising radiation absorbed during fracture reduction. In addition, there are advantages in terms of faster fracture recovery characteristics due to the usage of external fixation [10-17]. Usage which is a necessity, in order to move the bone fragments and have a safe reference on the bone structure, pins have to be inserted in the patient’s bony structure.

There are many fracture typologies, but this work focuses on those in which the diaphysis has been misplaced by the trauma. The mechanical conditions granting fracture healing are the proximity of the fractured bone segments coupled with a certain degree of micro movements allowed, because these facilitate callus formation [18].

These conditions are fulfilled, with the conventional methodology, by a fracture reduction intervention conducted under fluoroscopy, followed by a period of immobilisation, obtained by rigid bandage (plaster) application. Using the methodology here described, bone alignment and stabilisation are simultaneously executed, thanks to the integration of our system with fracture reduction using the fixation devices, that are increasingly used as a practical method to solve "difficult" fractures.

2 Problem Formulation

In order to obtain the "Enhanced Reality" representation of the process of fracture reduction, two initial X rays of the region concerned, where the fixator clamps are visible, have to be taken and recorded on a computer. Coupled to the clamps, two scaling devices and a goniometric measuring device have to be added before taking the initial pictures, or eventually, immediately after, taking care not to move the patient while connecting the clamps to the measuring device.

Once the initial images are transferred to the computer, the bone profiles have to be located in the pictures, together with the six points characteristic of the scaling devices. Next, the computer, knowing the reciprocal position of the scaling devices key points through the measuring device, will compute actual picture scales, also determining the coordinates of the two points of observation [19]. The initial position of the distal bone with respect to the distal side of the measuring device will then be computed. From this point on, the doctor will be able to observe the new position of the bone in the initial picture scale on the computer screen, and this on both planes of observation, obtaining a 3D representation.

An alternative approach to this problem was the development of a reduction robot, which was controlled by the doctor via knobs, while the patient would remain under fluoroscopic control [20]. The success of this system was, however, not great, due to the fact that, in this case, the doctor in some way loses the full control of the operation, since this equipment was lacking an haptic interface, making impossible the perception of the forces applied, and does not "see" the patient directly, as is instead permitted by the application of the procedure presented in this paper.

3 Problem Solution

The basis of the system, a six degrees of freedom goniometer, interfaced to a computer, on each extremity of which both a fixator clamp and a scaling device are mounted (Fig. 1) [21]. A new system is under development [22], in which the degrees of freedom used will be twelve, in order to obtain a self balancing system made by two six degrees arms each of which is self balanced, but coupled with encoders of far greater precision (16 bits rather than the initial 11 bits of this experiment).

The measuring device, coupled to a duly programmed PC, allows the effect of the movements imparted by the doctor to the bones to be computed, showing on the computer screen, the new relative position of the bone segments in real time and with good precision. Let us now explain in greater detail how the system works, (patent applied) [23].

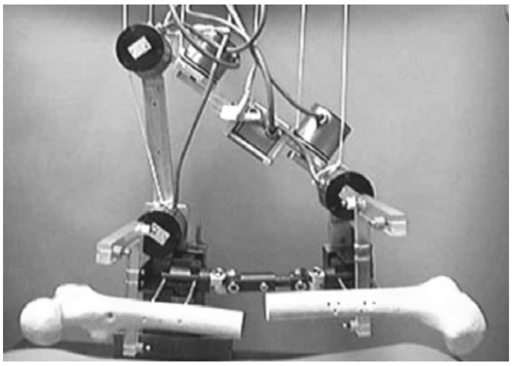


Fig.1 - View of the Enhanced Reality system

First, as already mentioned, it is necessary to acquire two radiographic or fluoroscopic images of the fracture region, on two planes approximately perpendicular (frontal and sagittal views), after installing the measuring device complete with scaling devices. This allows a three dimensional analysis of the situation. Each of the images should also display the position of the six reference points of the scaling device (Fig. 2).

Three of these reference points are connected to the proximal side of the measuring device. Specifically, one is placed at the origin of the frame of reference, fixed to the proximal side (absolute), and the other two at a fixed distance from the origin and along two of the axes. Similarly the other three, fixed to the distal side of the measuring device, are placed, one at the origin and the others along two of the axes of a second frame of reference (relative). Naturally from the encoders measurements it will be possible to know the position of the second set of points with respect to the frame of reference fixed to the proximal side (so-called absolute). At this point the position of all six points with respect to both images will have to be determined.

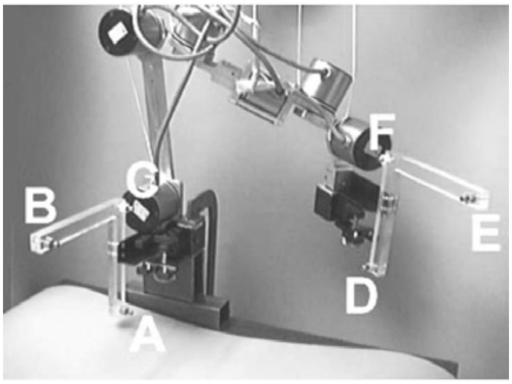
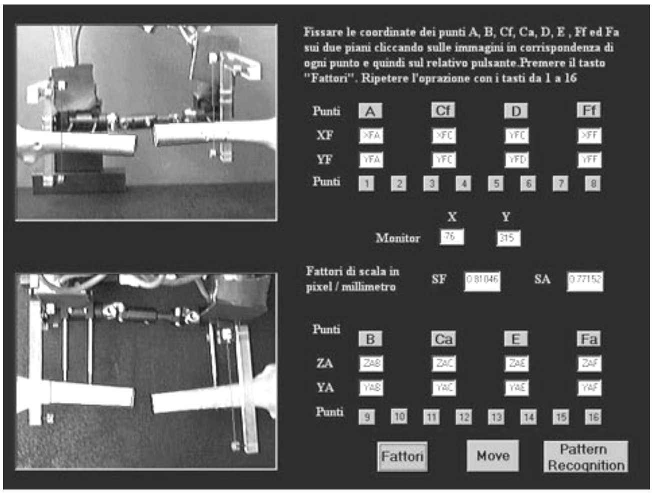


Fig.2 - Measuring device, showing the scaling devices, connected to the end clamps, with the six characteristic reference points

Considering the experimental nature of this project, photographs were used instead of radiographs. The perfect orthogonality of the picture planes is not so important, even if it was preferable in these first attempts. With reference to Figure 3, we then define the sagittal (index s) view of the image in the YZ plane, and the frontal (index f), the one parallel to the XY plane, having Y the direction of the diaphysis.

Once the images are acquired as bitmaps by the computer, it is necessary to determine the relative scale factors, in order to correctly represent the movements observed through the goniometer on the picture scale. Due to the variable focusing distance, it is necessary to compute two different scale factors, one for each view.



Fissare le coordinate dei punti A, B, Cf, Ca, D, E , Ff ed Fa sui due piani cliccando sulle immagini in corrispondenza di ogni punto e quindi sul relativo pulsante.Premere il tasto "Fattori". Ripetere l'oprazione con i tasti da 1 a 16

Punti	A	Cf	D	Ff
XF	XFA	XFC	YFC	XFF
YF	YFA	YFC	YFD	YFF

Monitor X 76 Y 315

Fattori di scala in pixel / millimetro SF 0.81046 SA 0.77152

Punti	B	Ca	E	Fa
ZA	ZAB	ZAC	ZAE	ZAF
YA	YAB	YAC	YAE	YAF

Fig.3 - Determination of the reference points on the scaling device and on the fractured bone

To do this, in this preliminary phase, the reference points on the scaling devices have been located using the mouse. Next, scale factors were determined as a ratio between the distance in pixels and the real distance as measured with the goniometer, naturally projected on the picture plane. In future, it will also be necessary to take into account perspective effects.

Together with the determination of the position of the six reference points, the origin of a new absolute frame of reference, coinciding with point C in Fig. 2, is established. A second relative frame of reference, centred on point F, is also established. Projecting those on the images two bidimensional frames of reference will be generated, that will be called XYs e ZYf (Fig. 4).

The bone contours are then determined, still using the mouse, taking the co-ordinates of four points per bone segment, referring the fixed part to the absolute frame of reference, and the mobile part to the relative frame. A new semi-automatic procedure of pattern identification will soon be developed.

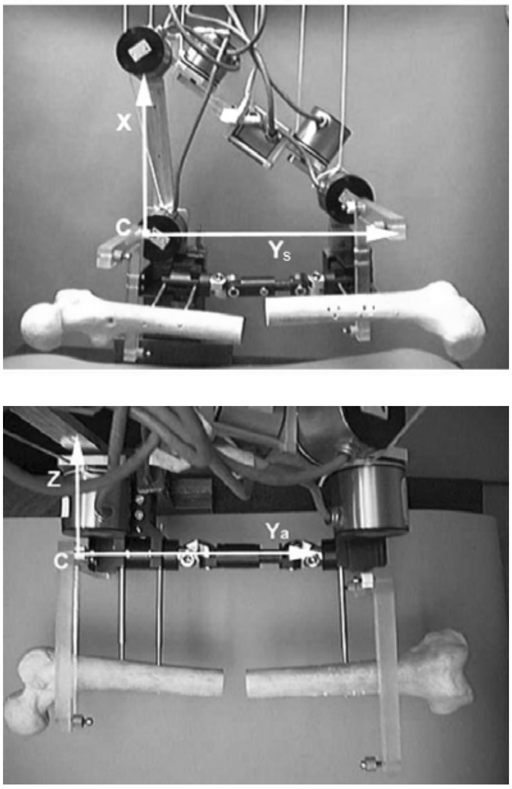


Fig.4 - Sagittal (upper) and Frontal (lower) views of the "surgical theatre"

3 Problem Solution

As previously mentioned, in order to determine relative motion between the proximal and distal bones, a six degrees of freedom measuring device made of six eleven-bit digital encoders has been used. A new lighter and more precise goniometer has been designed, and was built. The instrument allows all six angles with a high rate to be measured, through an ad hoc board, coupled to an Analog Devices Industries RTI 817 board, and under computer control. Migration to National Instruments boards is also underway. The acquisition program is written in Visual Basic for Windows.

Finally, the fixator D.F.S [24], coupled to the measuring device, allows the clamps to be moved, blocking one degree of freedom at the time, working in sequence on perpendicular planes.

Inserting the angles supplied by the encoders in the equations used to describe the co-ordinates of a point [25] - fixed to the relative frame of reference with respect to the absolute frame of reference - the co-ordinates of the origin of the mobile frame of reference (Xp1, Yp1 e Zp1) are determined with respect to the fixed one, and vice versa. It is now necessary, in order to know the absolute co-ordinates of any point taken as fixed to the relative frame of reference, to determine the co-ordinates of this point (for instance the points belonging to the "mobile" bone fragment) with respect to the mobile frame of reference in the initial situation.

Because this condition is satisfied "a priori" only for points D, E and F belonging to the mobile scaling device, it is necessary to compute the relative co-ordinates of the points belonging to the distal bone fragment.

Now these co-ordinates in their initial values are known from the pictures, and using the scale factors, in terms of absolute co-ordinates. Using the directional cosines of the axes centred on F and presenting the x axis along the F-D direction, the z axis along the F-E direction, and y perpendicular, this co-ordinate transformation is easily produced.

Once the co-ordinates of the points representing the distal bone profile are computed, and those of the diaphysis, the new co-ordinates of these points can be computed, while the operator is moving the mobile frame of reference, projecting scaling and plotting them on the picture that represents the operating theatre in real time.

The following program screen shows two images representing the two projections of the bone fragments on the sagittal and frontal plane, together with a third image of a video camera allowing real time visualisation of the actual motion in the sagittal plane. This allows a clear comparison of Reality versus Enhanced Reality, proving that the system works. Due to the imperfect operation of our video acquisition board, it was possible only to obtain images of this process holding a video camera in front of the computer screen, thus the quality of the images produced is far from perfect. Clearly the computer image was changed at a finite rate (100 Hz), more than enough to give fluidity to the image.

The extreme simplicity of the graphic scheme is also due to the need to accelerate the representation. Clearly, movies of this process were obtained and will presented at the conference, but for the moment in fig. 5 only 4 of the more than 100 subsequent frames obtained in one of the experiments are shown.

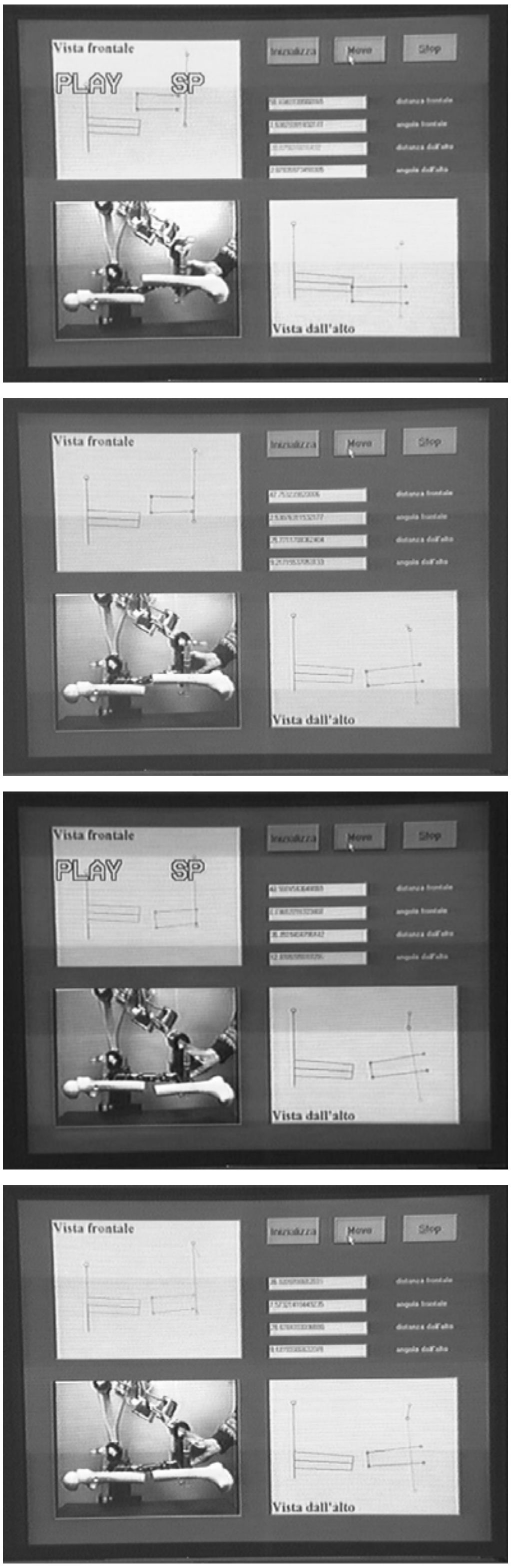


Fig. 5 - Sequence of frames from the Video registration of a comparison between Reality (lower image) and Enhanced Reality (upper image)

In real life, once the alignment is obtained, the clamp position will be blocked with the fixator, and the system detached from the patient.

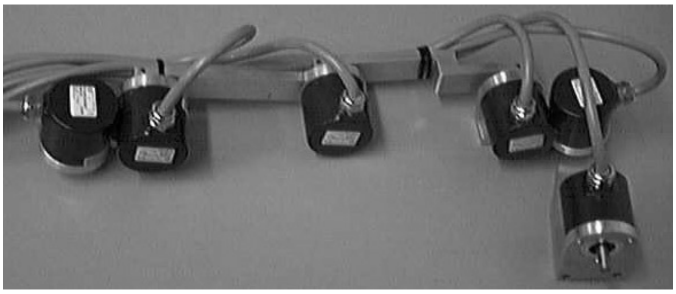


Fig.6 – New version of the goniometric device

As can be seen, the system works, even if it needs improvements. A second set of experiments was performed using a 13 bit goniometric device [26], shown in Fig. 6, and the results of this second test were non dissimilar, but allowed to discover errors in the experimental set up previously not noticed, thanks to the software developed to compute the center of observation of an image, given six points of known coordinates [19], which was a pretty good test of the precision of this system, shown in Fig. 7.

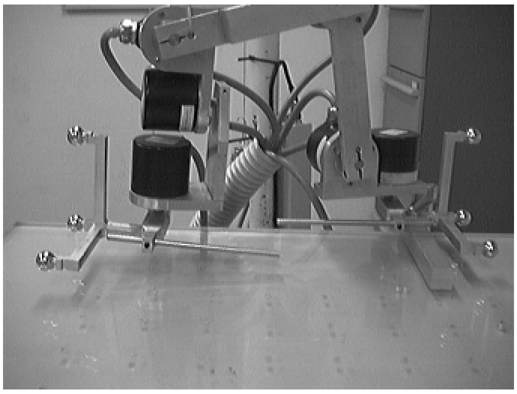


Fig.7 – New experimental set up for “fracture” reduction

4 Conclusion

The work is far from complete. Apart from the new goniometer and a general revision of the procedures, once this will be operative and tested, it seems necessary to use semi automatic procedures to define both bone and reference point positions. Automatic computation of distances between the bone fragments and angles between the diaphysis of the two fragments can also be easily added.

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