ATLAS GUIDED NEUROSURGERY

by

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ATLAS GUIDED NEUROSURGERY

ABSTRACT

In this work, a computer interface is developed to deform atlas overlays, so as to make them fit to a certain case, namely a particular patient's anatomy for pre-operational target determination for neurosurgeries.

The integration of CT images with atlas overlays is the first achievement.

~~Secondly, the ACTR (Atlas-CT registrar) is equipped with many abilities to manipulate the overlays and CT images in all axial, sagittal and frontal views, namely, to zoom them, to span~~ in ~~the zoomed one, to scroll through atlas overlays~~ and ~~CT images, and to place the overlays on their proper locations on sagittal CT image. One of the most powerful features of ACTR is its independence to zooming factor during placing process of overlays onto sagittal CT image, which is done respect to coordinates of Anterior and posterior commissure. It is also independent of zooming factor during the selection of analog points from a zoomed CT image and an atlas overlay. Deformation is done by analog points with no necessity of the measurement of the dimensions of the region of interest on CT console or~~ film ~~or of modeling of the cortical surface of~~ the patient like in ~~earlier versions of such tools, and the utilization of a~~ 2-D ~~deformation~~ fed ~~by~~ the ~~coordinates of analog points.~~

In terms of time, the system is able to calculate the coordinates of region of interest within a quarter of an hour with a great range of selection for region of interest.

Keywords: Computerised Tomography , Atlas Overlays, Image Deformation, 2-D deformations

ATLAS GÜDÜMLÜ SİNİR CERRAHİSİ

ÖZET

Bu çalışmada, sinir cerrahisinde ameliyat öncesi hedef tespiti amacıyla kullanılacak bir bilgisayar programı geliştirilmiştir. Program atlas görüntülerini belli bir hastanın anatomisine uyacak şekilde bozar.

CT görüntülerinin atlas görüntüleri ile birleştirilmesi ilk adımdır.

ACTR içinde tanımlanmış olan işlevler kullanıcıya her yöndeki CT görüntüleri içinde hareket etme, detaylama yapma, detaylama içinde gezinme olanağı sağlarlar. Ayrıca atlas görüntülerini, sagital CT görüntüleri üzerinde anteriyor ve posteriyor comissura noktalarına göre hesaplanan yerlerine yerleştirir. Bu yerleştirme sırasında detaylama katsayısını göze almak gerekmez, çünki ACTR detaylama katsayısından bağımsız olarak işleyebilir. Görüntü deformasyonu için CT görüntüleri ve atlas görüntülerinden benzeşen noktalar (analog points) şeçilmelidir. Bu görevi yerine getiren benzer sistemlerde gerekli olan CT konsolu üstünden ilgilenilen noktanın boyutlarının ölçülmesi zorunluluğu ortadan kalkmıştır.

ACTR, üzerine görüntüler yüklendikten sonra 15 dakika içinde istenen bölgenin koordinatlarını verir.

Anahtar Sözcükler: Bilgisayarlı Tomografi (CT) , Altas görüntüleri ,Görüntü deformasyonu, atlas görüntüleri, bilgisayarlı tomografi görüntüleri

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LIST OF ABBREVIATIONS

AC	Anterior Commisure
ACTR	Atlas-CT Registrar
DID	Drug Induced Dyskinesia
GABA	Gamma-amino-butyric-asid
GP	Globus Pallidus
L-Dopa	Chemical Precursor of Dopamine
MRI	Magnetic Resonance Imaging
PC	Posterior Commisure
PD	Parkinson's Disease
SN	Substantia Nigra

I.INTRODUCTION

I.1 Motivation

The results of a literature survey for this work have revealed a significant fact. The tools, which are designed for the purpose of pre-operational target determination for neurosurgeries, are somehow not enough for the purpose [1][2][3]. Pre-operational target determination, with a rough explanation, involves the process of deformation of brain atlases to make them fit a particular case, namely the anatomy of a particular subject. Deformation is achieved by two sets of data, the first of which selected from subject, to which the atlas is going to be made fit, and the second of which selected from the brain atlas. However, current tools have disadvantages like deforming the brain atlas by outer cortical surface [1], which is a long and cumbersome process due to mathematical modeling of the surface, or by the anterior commissure-posterior commissure line deviations, which is a very rough approach and 1-D deformations [2], or by measurements of the dimensions of ROI on CT console which can insert errors in the calculation of target coordinates due to possible mistakes during these measurements on CT or scanner screen [3].

Furthermore, the current usage of 1-D deformations and AC-PC line deviation deformations by neurosurgeons in Turkey indicates the necessity of a computer program with a computational ability for the calculation of coordinates of a target by utilization of 2-D deformations, which again operates with data selected from CT images and from brain atlases so as to minimize the errors due to human-being interference, e.g. measurements done by hand, and with the usage of more specific characteristics of a subject, namely the corners of a pattern of subject's brain as viewed in CT images to match them with their analogs in brain atlas.

The other main necessity is to integrate CT or MR images with brain atlases to get a less dead reckoning insertion into a brain of a subject. The requirement arises because the limitations inherent in imaging modalities like X-Ray CT and MRI. Even, they are both complex and developed imaging modalities, they have both their own limitations [4]. MRI is good at soft-tissue imaging, which makes it a very strong candidate for pre-operational target determination, some inherent shortcomings due to chemical shift, magnetic field uniformity this candidacy weakens. On other hand, X-Ray CT, imaging without distortions and without soft tissue details, becomes the correct choice. However, a problem arises

here: the loss of soft tissue details. This is another reason for the construction of such a tool with the ability of integrating brain atlases with CT images.

I.2 Thesis Outline

In the second chapter of the work general information about Parkinson's disease is given. This chapter involves the classic symptoms of PD, its treatment methods, the shortcomings of pharmacological ones, why operational ways are still necessary, why such deformations are utilized, are mentioned.

The second chapter bears the name "General Overview of Stereotaxy". This chapter tells the main properties of stereotaxy and stereotactic systems in detail.

The third chapter includes a sample application with ACTR. The properties of ACTR are displayed in the chapter explicitly. ACTR as system uses 2-D deformations, which utilizes both affine and distortions in 2-D.

The last chapter is indented for the descriptions of results, what the powerful sides of ACTR, how many of the goals of the thesis mentioned in the motivation part are achieved.

II.GENERAL REVİEW OF PARKINSON'S DISEASE

II.1 A brief background of Parkinson's Disease

Parkinson's Disease was first described in detail by James Parkinson in his essay "Essay on the shaking palsy". Afterwards, the disease started to be called as Parkinson's disease (PD). Actually, it is not obvious how prevalent the disease in the nineteenth century and before, but there are some speculations about its first appearance in the eighteenth century. On the other, the ancient Indian Medical system Ayurveda has some descriptions of a disease with similar properties to those of PD [5].

PD is correlated to a group of symptoms in patients, which are described below. Unfortunately, up to for the time being, the underlying cause is still unknown; therefore, the term idiopathic is used for PD. There is a general belief that true PD does not have a clearly defined cause [6]. On the other hand, there are some cases where the aetiology is much clearer, and these cases are referred as parkinsonism or parkinsonian syndromes.

II.2 Clinical Description

"Parkinson's disease is a disease of later life with a mean age of onset of about 60 years of age. It affects about 0.15 per cent of the total population but the prevalence increase to 0.5 per cent of those over 50. PD is a progressive disease with gradual exacerbation of symptoms [5]." There is no evidence for dietary of infectious influences in PD. Until recently, PD was considered as a non-inherited disorder. However, recent studies on families where PD seems to be inherited have been done. On the other hand, increased incidence of PD has been linked variously with rural environments, drinking well water, industrialization, and pesticide usage. Another important fact has been explored that there is decreased incidence for cigarette smokers.

The classical features of PD are tremor, rigidity, and disturbances of movement (bradykinesia and akinesia). The tremor is seen as a resting tremor in the limbs and disappears on movement or during sleep, whereas increases depending on the anxiety of the patient.

Even though the classical features of PD listed above do not include cognitive changes in the patients recent studies have revealed specific alternations in some cognitive abilities early in the disease. As the disease progresses, an increased risk of dementia is possible.

II.3 Neuropathological Observations

Postmortem examination of the brains of PD patients shows a specific degeneration of the substanstia nigra (pars compacta) (Figure 2.1). In addition, round eosinoplic intraneuronal inclusions containing filamentous material called Lewy bodies are frequently in the substantia nigra and the locus coeruleus.

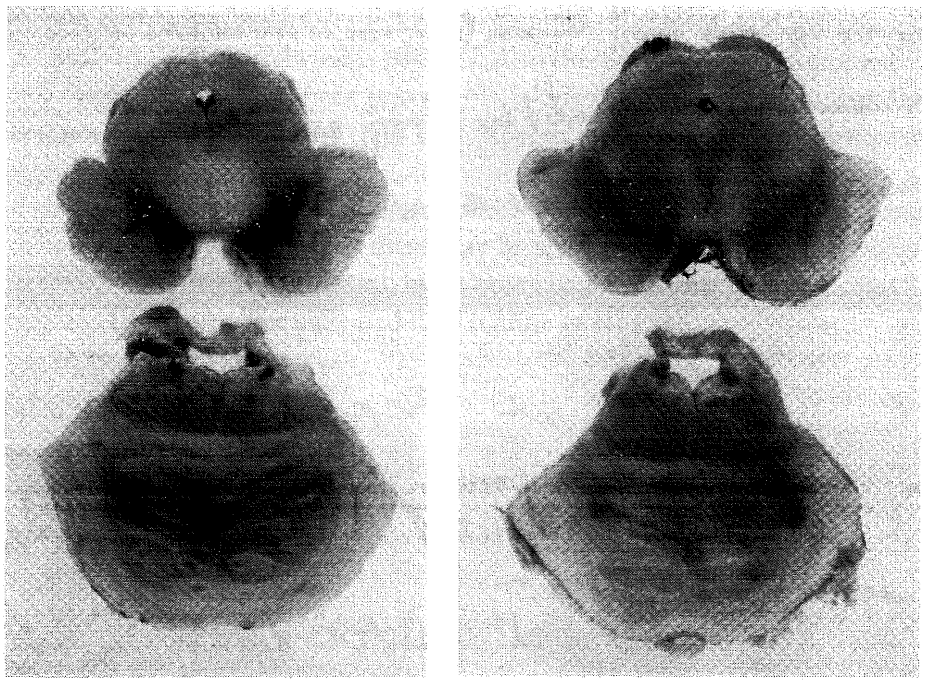

Figure 2.1 The substantia nigra and locus coeruleus of normal (lefthand panel) and PD (righthand panel) patients. The upper photograph in each panel shows a section through the mid brain and the loss of pigmented cells in the substantia nigra can be clearly seen in the parkinsonian case. The lower photograph in each panel shows a section through the pons, illustrating the locus of coeruleus [5].

In 1960 Ehringer and Hornykiewicz measured dopamine levels in human brain and showed there to be a significant (>50 per cent) depletion of dopamine and of its metabolite homovanillic acid in the caudate nucleus, putamen, substantia nigra, and to a lesser extent in the globus pallidus of PD. The integration of this information with the nigral degeneration resulted in the suggestion that in PD there is a specific loss of the mesostriatal

dopamine pathway (a loop of neurons in which dopamine roams, whereas there are ones defined in the brain), which runs from the substantia nigra to neostriatum (caudate nucleus and putamen) and globus pallidus. The loss of this pathway can account for many symptoms of the disease due to the involvement of neostriatum (caudate nucleus and putamen) in the control of movement. The loss of dopamine in the straitum can now be observed on living patients using positron emission tomography (Figure.2.2)

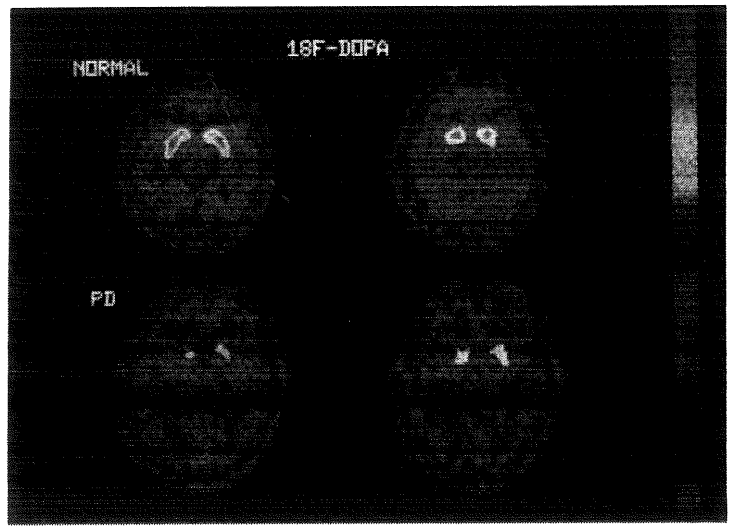

Figure 2.2 Positron Emission Tomography (PET) of scan of brain dopamine levels. The patients were given [^{18}F]L-DOPA which accumulates as [^{18}F]dopamine in the striatum and can be visualized from the positron emission of ^{18}F. The upper panel shows normal scans whereas the lower panel shows scans from a patient with PD. The loss of dopamine storage subsequent to loss of mesostriatal dopamine neurons is clear in the patient with PD. The loss is greater in the putamen than in the caudate nucleus. The pictures show horizontal sections through the stirata [5].

Consequently, the major effect in PD is loss of the mesostriatal dopamine pathway with less major alternations in mesocortical dopamine and locus coeruleus noradrenaline pathways with losses of cholinergic pathways in patients with Alzheimer type dementia.

II.4 Treatments for PD

In broader terms the treatments of PD can be grouped in two main groups: pharmacological treatments and surgical treatments.

II.4.1 Pharmacological Treatments

II.4.1.1 L-Dopa

The discovery of the depletion of the striatal dopeamine offered this pharmacological treatment, the replacement of the lost dopamine. Since orally administrated dopamine cannot penetrate the blood-brain barrier, the precursor of dopamine, L-DOPA is to be administrated. The L-DOPA is converted to dopamine in brain. Carllson and colleagues had shown in animal experiments in 1957 that administration of L-DOPA would reverse a brain dopamine deficiency [7]. From 1961, tests with L-DOPA began in patients with PD. Early reports using low doses were encouraging but the start of usage larger doses (4-16 g a day) by Cotzias and colleagues revealed the problems with L-DOPA treatment [5].

L-DOPA treatment with a dose of 1 g a day and peripheral decarboxylase inhibitor is very successful in reducing many symptoms significantly although there are some side effects such as dyskinesias, psychiatric disturbances, and a reduction in efficacy with time, which are main problems of L-DOPA treatment [5].

II.4.1.2 Selegiline (Deprenyl)

This drug, which is a specific inhibitor of monoamine oxidase B, has been proposed for therapy in PD depending on its reduction in the breakdown of dopamine resulting in its action. Results are variable: the drug on its own does not seem to have a major acute effect although it seems to potentiate the action of L-Dopa and reduce fluctuations in response [5].

II.4.1.3 Amantadine

This is an antiviral drug, which can be used in treating only in PD. It is more useful than the anticholinergics that it increases dopamine release. It is also a potent antagonist at the NMDA subclass of glutamate receptor [8].

II.4.2 Surgical Treatments for PD

II.4.2.1 Neural Transplantation

Neural transplantation is a surgical treatment in which dopamine-producing fetal cells are implanted in the brain. The benefits of transplanting fetal cells into the brains of PD patients have been demonstrated in studies conducted in both Sweden [9] and the United States [10]. These studies concluded that fetal tissue can be safely transplanted into the human brain, and may provide dramatic improvements in functional ability. Most patients have shown increased sensitivity to PD drugs beginning 1-3 months after the fetal cell transplant and as a result significant reductions in L-DOPA dose are common. 6-12 months after the operation, patients report smoother and more predictable control of their movement. In some patients, speech and walking have been restored; although in no case have patients have been cured of PD.

Techniques for transplanting fetal cells into the human brain are still experimental and can only be performed at selected research centers with experience in this area. There are also risks associated with any surgical procedure and consequently surgery represents only one of many therapy options.

II.4.2.2 Deep Brain Stimulation

This neurosurgery consists of placing an electrode into the VIM nucleus of thalamus or GPI or into STN according to the symptoms of the PD patient. The electrode is then connected to an implanted device in the chest, similar to a cardiac pacemaker that sends electrical signals to the brain in order to control the tremor and other symptoms respectively. It is postulated that electrical stimulation will break the cycle of over-activity the cells in these regions of the brain. This technique is a nondestructive form neuro surgically inactivating brain regions thought to be responsible, in pan, for the motor difficulties caused by PD.

II.4.2.3 Thalamotomy

In thalamotomy, the goal is to permanently abolish tremor or other disabling involuntary movement disorder such as hemiballismus, chorea or dystonia by placing a small lesion in the ventro-lateral portion of the thalamus.

There is a considerable amount of clinical evidence that lesions in posterior portion of ventro-lateral thalamus are quite effective in alleviating tremor and lead to improvement in rigidity although bradykinesia is either unaffected or possibly worsened by such lesions Thalamotomy can alleviate tremor in the body opposite to the side of the brain that is operated upon with up to 80 percent effectiveness [11-13]. These findings support the contention that the best candidates for thalamotomy are patients with tremor-predominant PD or those with incapacitating benign essential tremor Problems with thalamotomy include loss of muscle tone, balance impairment, and speech impairment These occur with greater frequency in the patients getting bilateral surgeries.

II.4.2.4 Pallidotomy

In pallidotomy, the goal is to abolish DID, tremor, rigidity and bradykinesia along with other motor manifestations of PD by placing a lesion in the ventral posterior UP. The ventro-lateral nuclei of the thalamus are excitatory to the cortex and hence it follows that excessive inhibition of the thalamus by an overactive OPI could result in clinical symptoms such as rigidity and bradykinesia. This model explains the rationale for pallidotomy, lesioning GPI and the ansa lenticularis relieves the excessive inhibition of the thalamus, which then presumably leads to the observed improvements in rigidity and bradykinesia. Collaterals of some corticospinal fiber project to the basal ganglia while the basal ganglia ultimately exert their effect by way of the corticospinal tracts. Nevertheless, lesions of the pyramidal system predictably result in paresis and spasticity, whereas lesions in the extra pyramidal system cause a distinct pattern of abnormalities in the initiation and maintenance of movement. These abnormalities have been classified as negative and positive symptoms. Negative symptoms include bradykinesia (abnorinal slowness of movement) akinesia (absence of movement) and loss of postural reflexes. Positive symptoms include findings such as tremor, rigidity and involuntary movements (chorea, athetosis, ballismus, and dystonia).

Since the hyperactivity of GPI is responsible, in large part, for the stiffness and slowness experienced by PD patients, and may also contribute to tremor. By destroying part of GPI, the basal ganglia system is "rebalanced" alleviating many parkinsonian symptoms [14].

Several centers in the United States and Europe are now performing pallidotomy. Pallidotomy is usually considered an option only when medication is no longer useful in controlling PD. After the pallidotomy procedure, patients have demonstrated improvements in mobility, gait, and balance. Reductions in DID and motor fluctuations have also been documented.

Pallidotomy together with all other surgical methods, is not a cure for PD; symptoms can eventually return as the degenerative process that underlies the disease continues, but the operation will most likely give the selected PD patients several additional years of functional mobility. Additionally if symptoms on the operated side worsen significantly, the operation can be repeated on the untreated side of the brain for a few more years of relief.

III. GENERAL OVERVIEW OF STEREOTAXY

III.1 The Definition of Stereotaxy

Even though Clarke who interestingly was not a surgeon himself suggested the use of mechanically directed instruments for surgery in the depths of the brain in 1920, the first intracerebral stereotactic operation was not performed until 1947 when Spiegel and Wycis introduced "stereoencephalotomy" for the treatment of intractable pain. The Leksell Stereotactic Instrument was introduced and used for the first time in 1949.

Stereotaxy is often considered the simplest and safest approach to the deep areas. It is a highly suitable technique for making deep functional lesions and often the only desirable method for biopsies, for the treatment of deep seated cystic tumors. Implantation of radioactive seeds for interstitial irradiation necessitates the precision offered by stereotaxy in order to comply with dose-planning requirements. With the development of the Leksell Stereotactic Gama Knife in 1968, which is based on the same principle as the open technique, the number of indications for stereotactic treatment has increased further. The very high precision of the Gamma Knife lends itself particularly well to small and critically located targets. Radiosurgery in functional disorders and in the treatment of vascular malformations in the brainstem are good examples of such targets. The combined use of the operating microscope and stereotactic guidance, microstereotaxy, can aid the microsurgeon in his dissection, resulting in better control and less trauma [14].

Stereotactic is a term to describe procedures done in precise and defined in a three dimensional space. The scull and most other types of tissues (bone, brain, lesion) can easily be extracted from standard CT data provided that their intensity contrast is high enough compared to the other tissues. The lesion to be reached can either be extracted from CT, MR and PET (Photon Emission Tomography). Conventional angiography, CT Angiography or MR angiography data can also be utilized for improved planning.

Technically satisfactory stereotactic Systems are now commercially available, the most popular being the CRW (Cosman-Roberts-Wells, Radionics, Boston, USA) and Leksell (Elekta, Stockholm, Sweden). In Figure 3.1 a CRW stereotactic system is shown [16]. With such devices, a probe can be introduced into a known part of the brain identified by imaging techniques and a knowledge of brain anatomy. A computer can be used to

generate a three-dimensional image so that the surgeon can choose the least damaging route to the operative site.

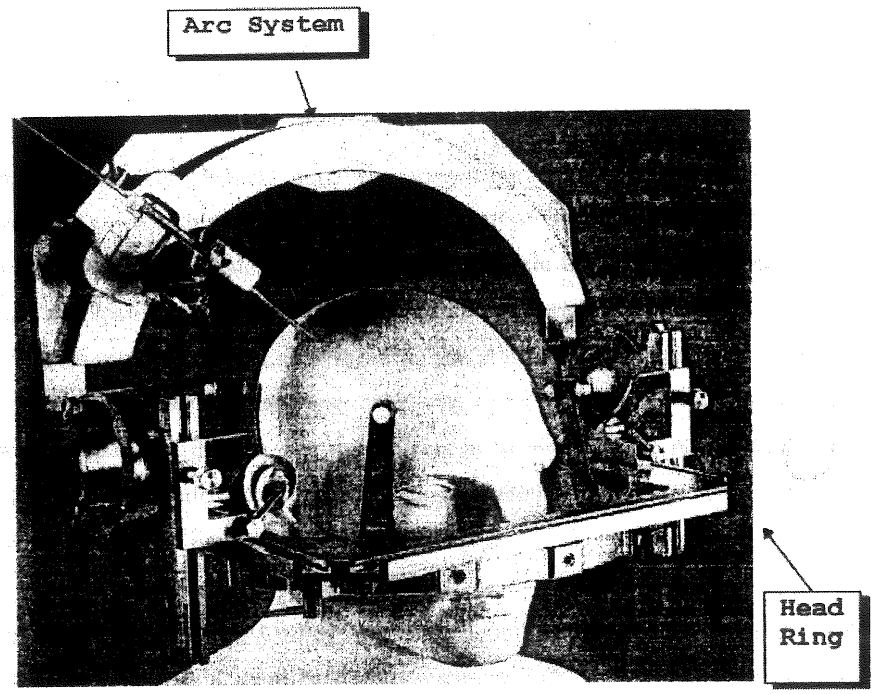

Figure 3.1 CRW Stereotactic System [16].

The basic principle of nearly all current stereotactic equipment is the firm fixation of the stereotactic apparatus to the patient's skull vault with metal pins. The second method is less invasive and allows the frame to be applied repeatedly so that stereotactic imaging, planning of treatment, and surgery may be carried out at different times. For stereotactic surgery local anesthesia can be used, but general anesthesia provides optimal control of intracranial conditions.

III.2 The Stereotactic Surgical system

In general, a stereotactic surgical system comprises four associated primary instruments:

III.2.1 Head Ring

The sharpened head screws on the head ring penetrate the scalp and head ring is attached to localizer frame. Figure 3.5 (a) and 3.5 (b) show the CRW head ring and the localizing rod system.

III.2.2 Localizer Frame

The localizer frame is a special purpose geometric device product. These systems are attachments made of plexiglas or a carbon compound in which special N, V, Z shaped markers are located, which are used to calculate the origin of the stereotactic system in all three spatial planes. With most stereotactic systems the coronal axis represents X axis, the sagittal Y axis, and the axial Z axis. Each point in the Cartesian coordinate system possesses a value triplet consisting of an X, Y and Z value. In this way every point in space can be defined. For the markers to be visible in the respective imaging technique, they must be made of contrast-producing material. These are primarily thin steel or cooper wires for CT and liquid substance for MRI [17].

Computing the Cartesian Coordinates of a point of interest using localizer with graphite Z the procedure of the coordinate transformation from a set of CT images requires the X and Y coordinates of the target to be found by measuring the distance of the selected point to the right hand side of the rectangle for X coordinate and to the posterior side of rectangle for the Y coordinate of the target. The third coordinate, Z, is found by measuring the distance between the posterior and middle fiducial points at each side of the localizer [8]. Since the lengths of vertical bar (be) and the diagonal bar (ac) on Z shaped localizer frame equal to each other the distance (ab) is projected on to the axial image in the distance (d) between the middle and posterior fiducial marks (ac), thus d gives the z coordinate as shown in Figure 3.2.

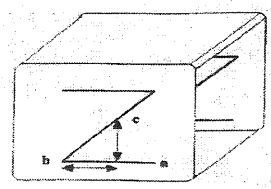

Figure 3.2 Computation of z coordinate using Z shaped localizer frame.

This frame attaches to the head ring, and enables target coordinate determination Anterior-Posterior (AP), Lateral (LAT), Vertical (VERT). The localizer's four vertical rods lie on the scanner's natural AP and Lateral axes. The scanned images come directly from the scanner console through a network or a magnetic media by using a transparency grid overlay on CT film hardcopy. The diagonal and vertical rods (in Figure 3.3) appear in the images and enable the measurement of VERT, LAT, and AP coordinates to be measured in the same way [16]. As an example, Leksell Head Frame and Localizer Frame are shown in Figure 3.4.

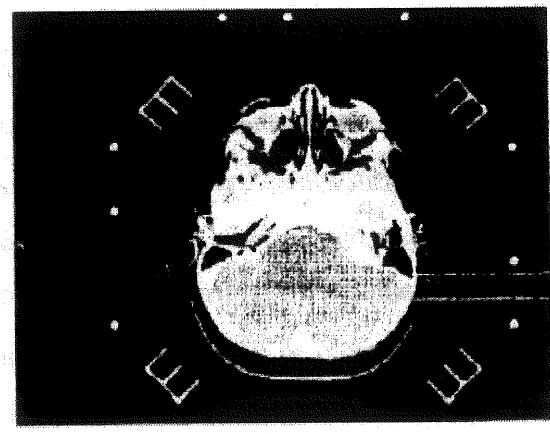

Figure 3.3 Fiducial Points on the image [15].

III.2.3 Target Centered Stereotactic Arc System

Being "target centered" means that once the AP, LAT and VERT coordinates are found they can be set directly on the three arc slides. In Figure 3.1 a stereotactic arc system is shown. The anatomical target will be at the center of the arc for all positions of the arc angles. Manipulation of the arc angles can easily pass a probe through a given burr hole to

reach the target without the need for a phantom base or any additional calculations. Changes in target values can also be made on the arc during surgery.

III.2.4 Phantom Simulator

This consists of a base ring and a moveable pointed tip, called the "dummy point". In Figure 3.5 (d) the simulator is presented. The dummy point can be fixed at any x, y and z settings. These settings are established when the coordinates for a target or an entry point are chosen with the arc system After entry of the localizing data obtained from the scan and the entry point coordinates obtained from the phantom simulator, the frame settings and distance to the target can be computed manually. After the arc system is placed on the phantom ring it will have the same relationship to the dummy point as for the anatomical entry point. Thus, the neurosurgeon can check the accuracy, direction and depth of the dummy point before attempting to reach the anatomical target in the patient [18].

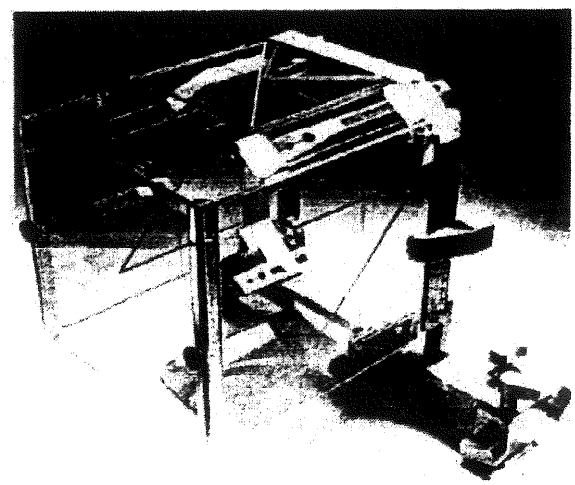

Figure 3.4 Leksell Coordinate Frame, Localizer Frame, and CT Adapter [16].

III.3 Stereotactic Applications:

1. Stereotactic Biopsy and Craniotomy
2. Interstitial Radiotherapy
3. Functional Neurosurgery
4. Stereotactic Radiosurgery
5. Frameless Stereotaxy

6. Frameless Isocenteric Stereotactic Laser Beam Guide for Image-Directed Microsurgery
7. An optical Navigator for Brain Surgery

III.4 Use of MR Angiography for Stereotactic Planning

Visualization and geometric evaluation of intracranial vascular anatomy are of vital importance for most stereotactic applications such as needle biopsies, radioactive seed implantation, functional stereotaxy, and stereatactic radiosurgery. Classic imaging modalities for this purpose are conventional digital subtraction X-ray angiographic techniques.

Flow compensated gradient echo sequences have been introduced into clinical MR protocols and have shown great potential in the assessment of angiographic anatomy. For the first time it is possible to use a single modality to image flow as well as stationary tissues.

The value of MR as an Imaging modality for stereotactic guidance is influenced by a variety of factors. As opposed to X-ray angiography, MR angiography (MRA) is a noninvasive technique that provides not only projection images, but also true volume data sets allowing three-dimensional (3D) visualization arid localization of any picture element in a 3D stereotactic coordinate system with a spatial resolution of smaller than 1.0 mm. Delineation of stereotactic targets and organs at risk may be performed in MR data sets with higher reliability than in CT images because of the better soft tissue contrast. However, MR has to cope with the problem of geometric distortion, introduced by magnet as well as patient related factors. Magnet related distortion is due mainly to magnetic field inhomogeneousity and gradient nonlinearities. Because of the improvement of the gradient system and magnet technology, the extent of distortion has been substantially reduced. Furthermore, correction algorithms that allow distortion in head scans to be limited to 1.0 mm have been developed. Patient related distortion factors include susceptibility and chemical shift artifacts and flow shifts. Optimization of pulse sequences and acquisition protocols (short TE) allows for minimization of these effects. MRA seems to be a suitable imaging technique for stereotactic planning procedures [19].

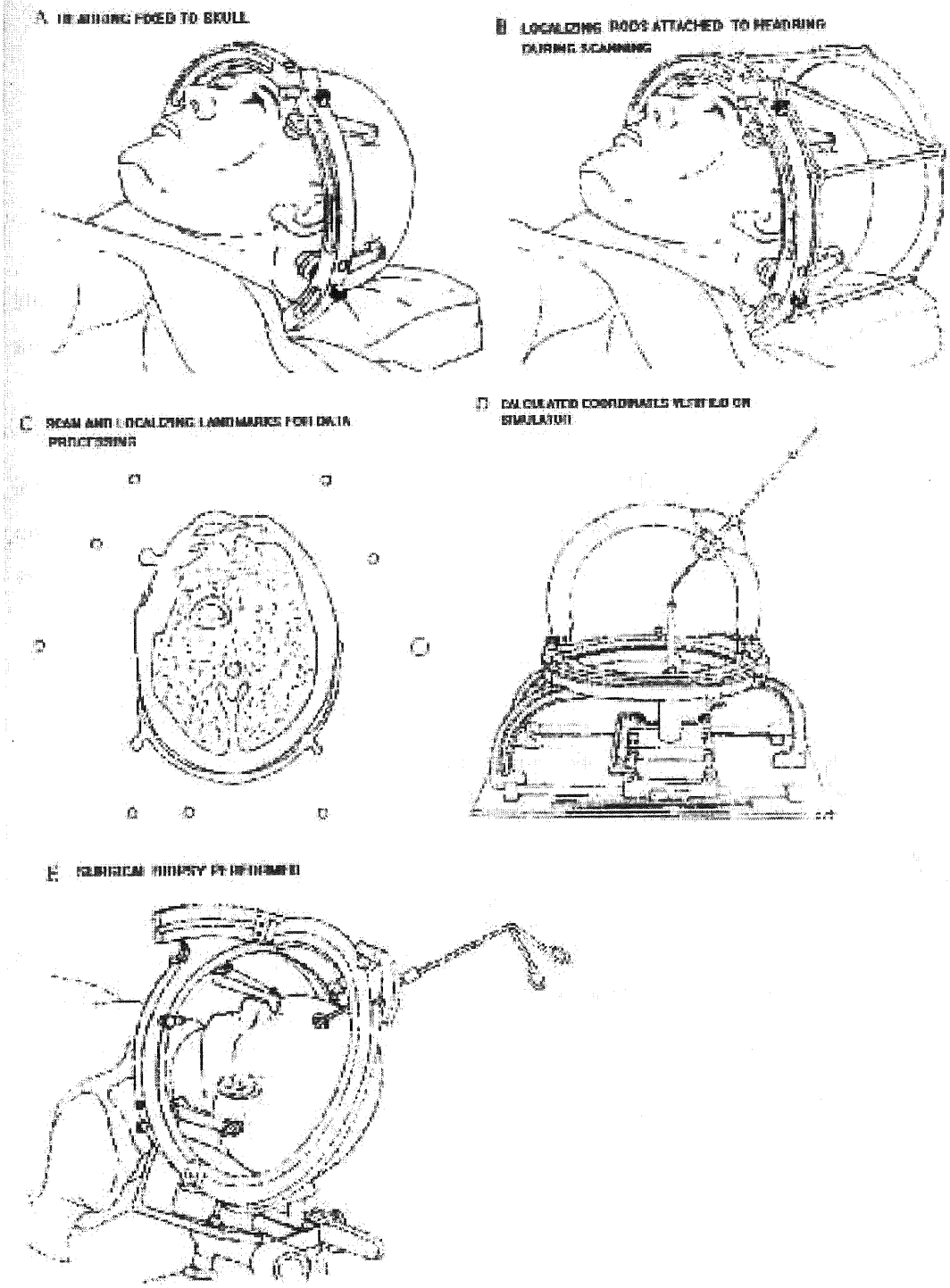

Figure 3.5 Diagrams showing the sequence of steps using the CRW stereotactic frame [16].

IV. ATLAS-CT REGISTRAR

IV.1 General Properties of Atlas-CT Registrar

Atlas-CT Registrar (ACTR) is the tool to achieve the goal of the work: integration of Atlas slices with CT images and the deformation of Atlas Slices to fit the subject's anatomy.

IV.1.1 Visional Properties of ACTR

ACTR divides screen into 5 distinct regions [20]. The one on the left upper corner shows a frontal plane of brain. On the one left lower, axial slices are placed; the middle upper demonstrates sagittal ones. The zoomed part of any one of sagittal, frontal, axial views can be seen on the middle lower region of the screen. On the other hand, the right hand of the screen is enterily devoted to place an Atlas Overlays on. Figure 4.1 showing the screen divided into its visional regions [20].

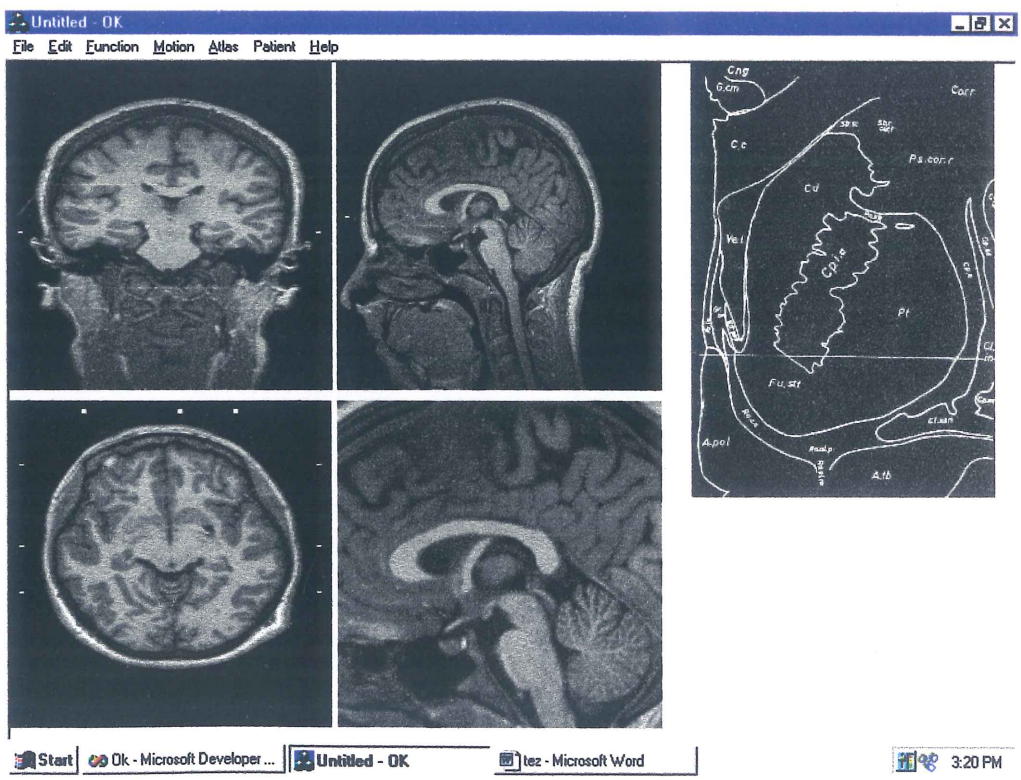

Figure 4.1 Regions on screen divided by ACTR.

On the menu bar of the ACTR, however there are 4 menus. These are from left to right: Function, Motion, Atlas and Patient menus. The detalied explanations of them will be given in the subseqent part.

IV.1.2 Functional Description of Menus

IV.1.2.1 Function Menu

The first menu utilised by ACTR is Function menu: In this one, some functions of ACTR are placed. Move, Move to... , Zoom times, Decimate, Enlarge , Select N Bars, Mark N Bars, Remove N Bar Marks, Deformation Points, Atlas-Frontal Display, Mark ROI on Atlas, Place, Pixel-Length Ratio, Target . Figure 4.2 shows the case where Function is clicked on for a subsequent choice among its options.

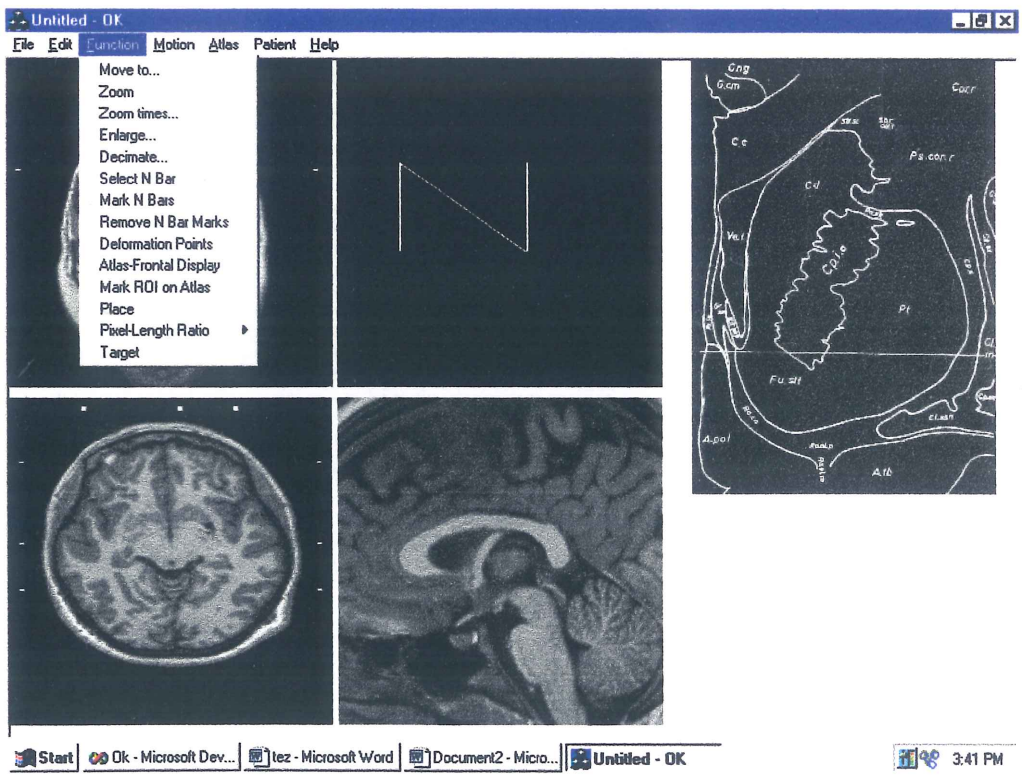

Figure 4.2 The case when Function menu is clicked on.

The first choice (respect to the top of the menu) is Move to... . As its name offers, it is used to move to a pre-selected slice selected from any of sagittal, axial, frontal or zoom parts. As an example, two cases are shown Figure 4.3 and Figure 4.4. An ordinary state in Figure 4.3 where the red cross on frontal slice shows where the user clicks on to "move to" corresponding slice on sagittal and axial views. The result of this action is demonstrated on Figure 4.4.

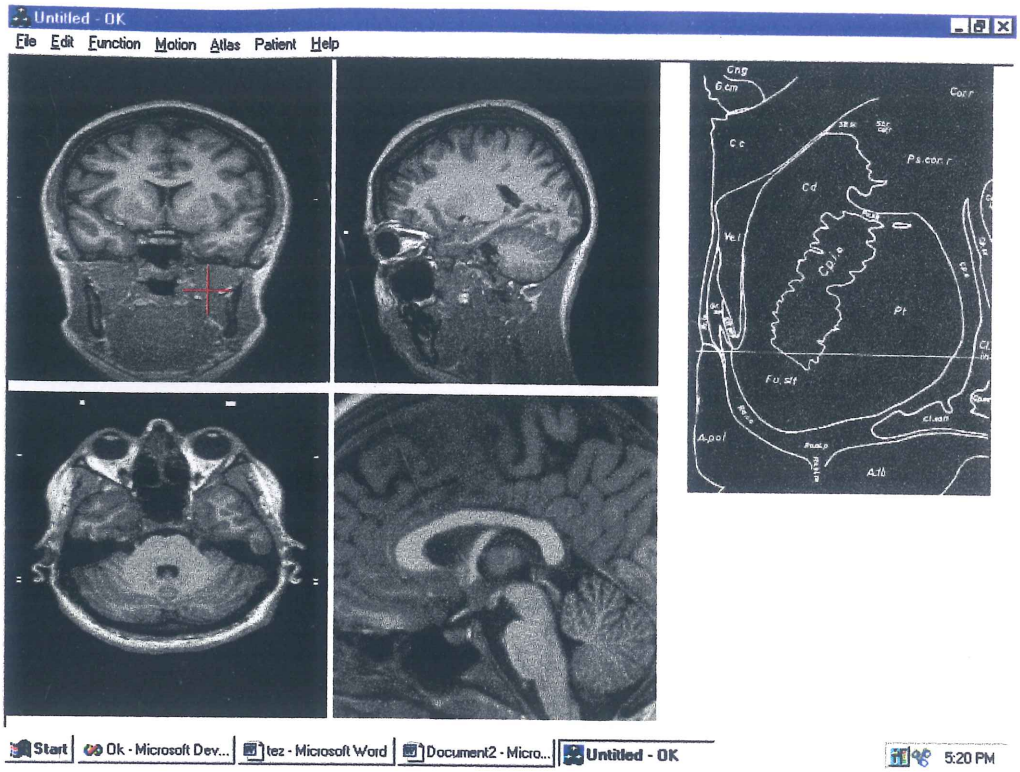

Figure 4.3 Red Cross indicates where the user wants to move to.

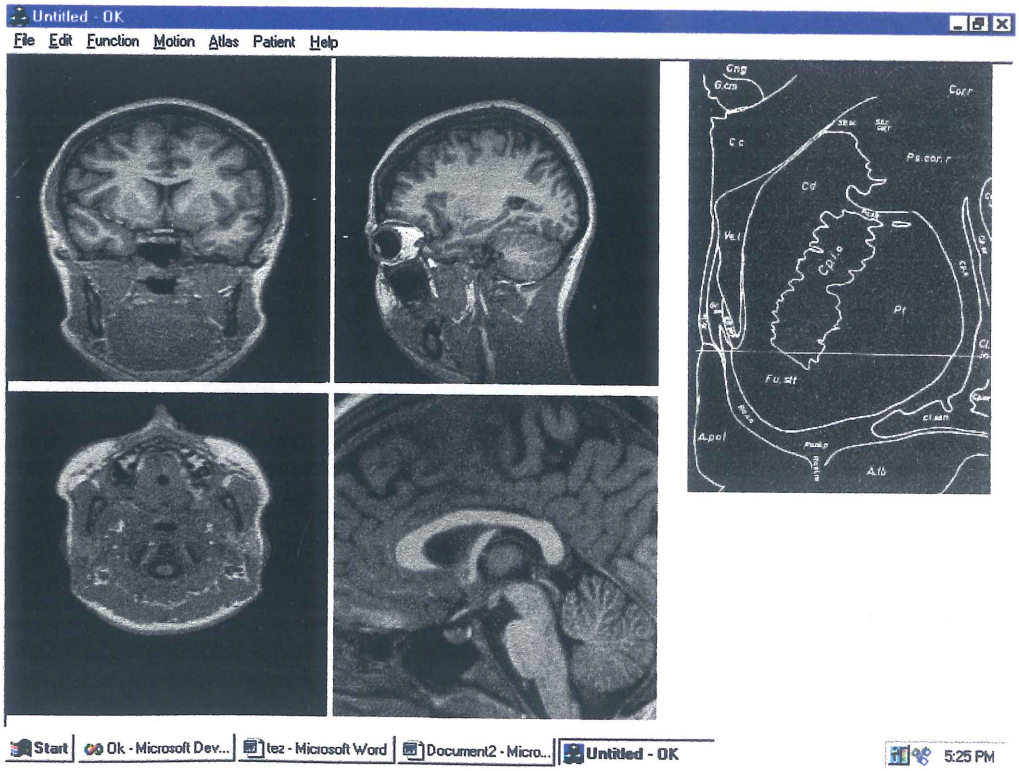

Figure 4.4 The result of "move to.." action.

The second option on the Function menu is zoom. It is used to focus a certain portion of any one of frontal, sagittal and axial views. To do so, the user should use the right button of the mouse to click on the point around which the zooming will be performed. The default value for zooming is 2. Figure 4.5 shows the 2 fold zoom of axial slice and its placement on middle lower portion of the screen.

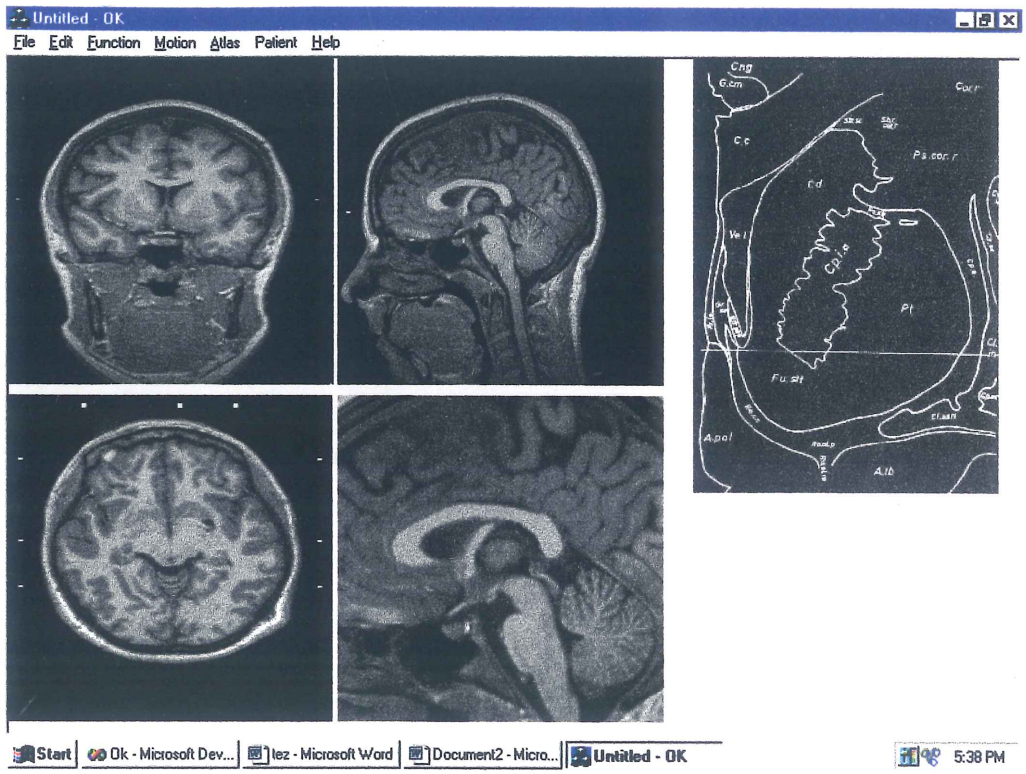

Figure 4.5 Sagittal view and its zoom on its designated part.

The functions below zoom are zoom times, Enlarge and Decimate. These functions are designed so as to enhance the zooming abilities of ACTR. Zoom times function enables the user to make a selection among zooming factor of the zooming algorithm. Actually, Enlarge and Decimate have opposite type of functions. Enlarge increases zooming factor by one whereas Decimate has a decreasing effect on zooming factor. For brevity the user has the usage of Alt++ [21] combination defined as the shortcut for an increment in zooming factor by one. Successive usage of the combination results in more zoomed views of the current portion. Figure 4.6 shows where the user has increased the zooming factor by 2 (it equals to 4) for the same zoomed portion in Figure 4.6.

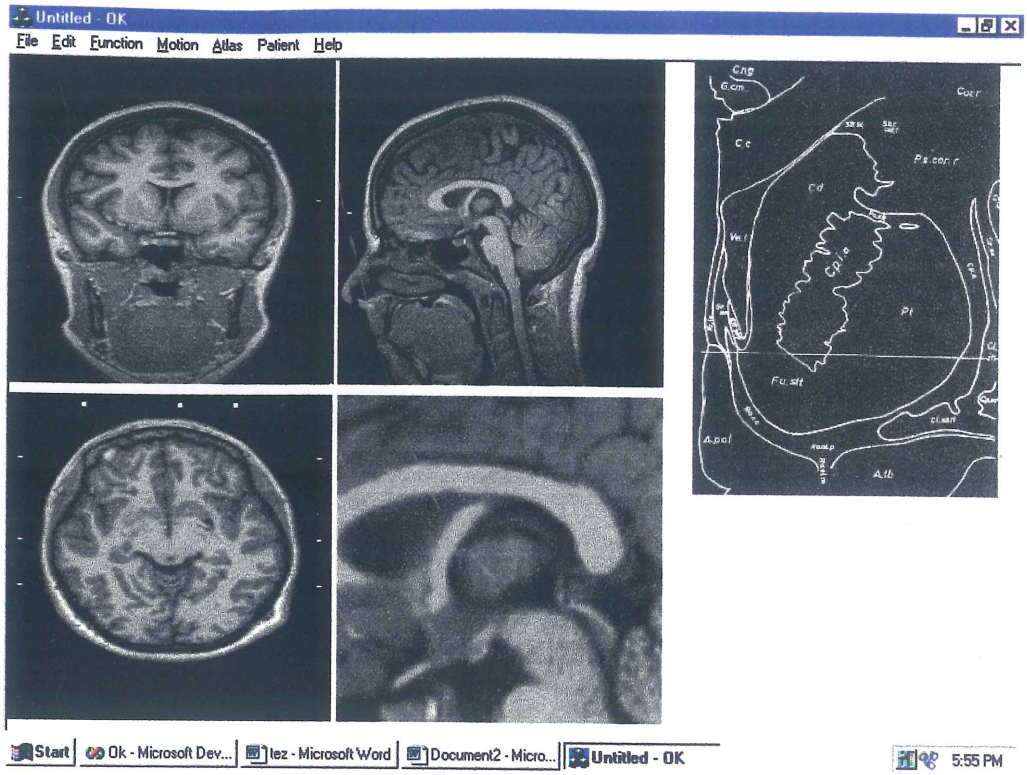

Figure 4.6 Case with a zooming factor two more than that of Figure 4.5.

The remaining options of this menu item are Select N Bar, Mark N Bars, Remove N Bars, Deformation Points, Atlas Frontal Display, Mark ROI on Atlas, Place, Pixel-Length Ratio and finally Target from Decimate function to the bottom of the list. Their roles in the progress will be clarified in "A Sample Application by ACTR". part hence.

IV.1.2.2 Motion Menu

This menu is designed to scroll through the slices of different views. Functions in this menu can be grouped into two main classes: the ones with motion of a single slice of a particular view (single slice movers) and the ones with combined motion (multiple slice movers). Sagittal, Frontal, Axial and Atlas selections are to be placed in the former and Zoom and Atlas-Frontal Slice in the latter. A general appearance of Motion menu is shown in Figure 4.7.

The functions of single slice mover members are obvious. For instance when the user clicks on Dextra sub-option of Sagittal option of the menu, only the current sagittal view is going to be moved one slice right and when Sinistra is chosen the current sagittal moves one slice left. The rule is the same for all other frontal, axial and atlas selections but differing in their effect to different views.

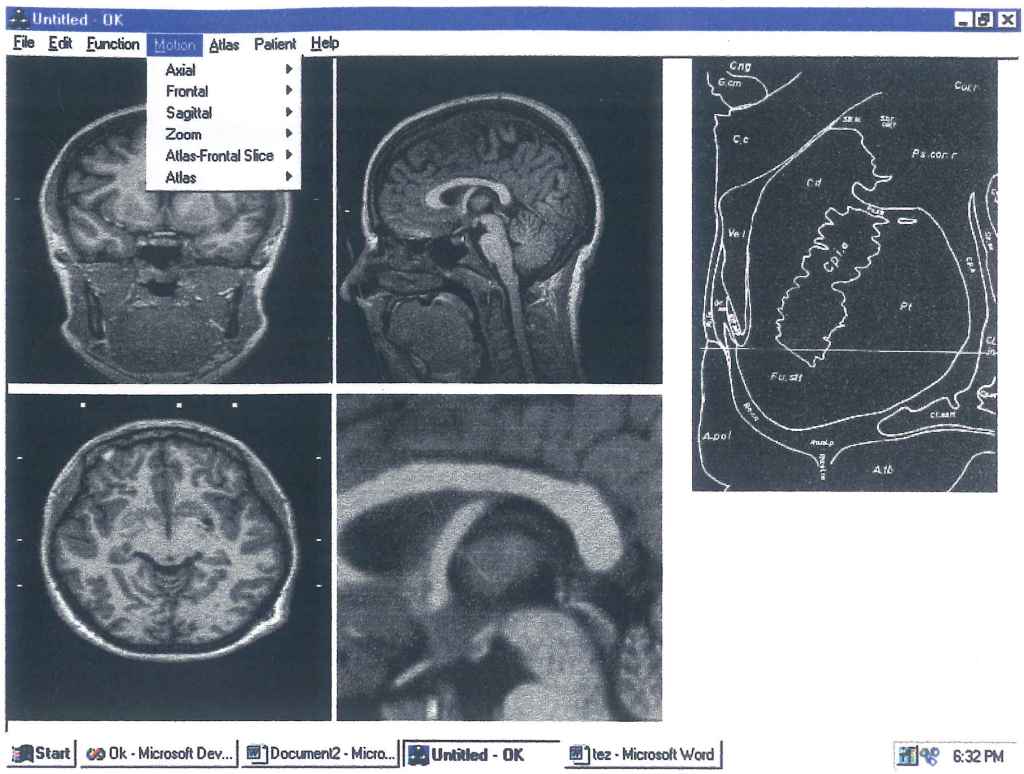

Figure 4.7 General Appearance of Motion Menu.

It is worthwhile to mention the functions of others members of motion menu in details. In a case like Figure 4.8 in which a certain portion of the axial is zoomed, to see one slice above axial slice with its zoom the user must the Zoom option and its braches named forward. The branches of Motion-Axial selection are displayed in Figure 4.8. Such flexibility is valid for all views. The other alternatives placed in the list, Up, Down, Left and Right have the mission of spanning for zoomed part.

The other member of multiple slice movers is Atlas-Frontal Slice option. Its function starts during atlas-frontal slice matching process. The coincidence of frontal CT image with its Atlas overlay is a crucial step during registration. Atlas-Frontal Slice button provides the user with a such a property by two different ways: either moving frontal CT view one by one to next nearest Atlas Overlay by selecting Forward on Frontal CT (or Backward on Frontal CT) or by a direct jump to nearest coincidence achieved by Forward (Backward) on Frontal Atlas. The pattern of the Motion option and Atlas-Frontal Slice sub-option is shown in Figure 4.9.

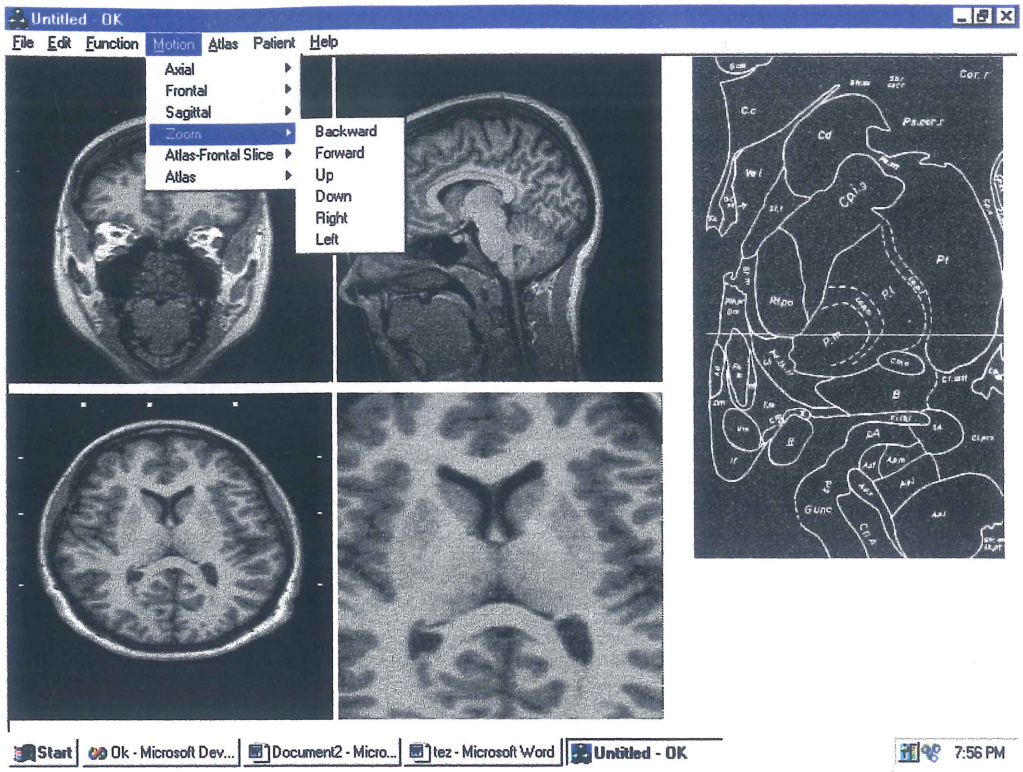

Figure 4.8 The status of screen when Zoom option of Motion is clicked.

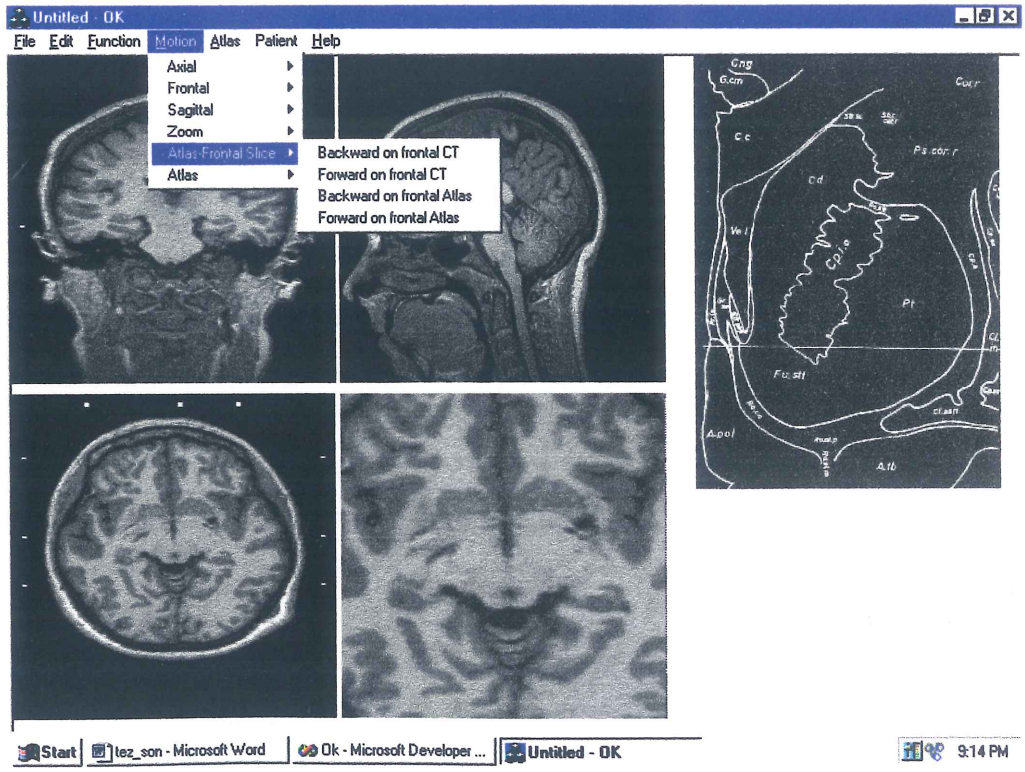

Figure 4.9 Details of Motion Menu.

IV.1.2.3 Atlas Menu

The Atlas menu bears the functions related to Atlas processes. It has 5 options in it. These are Display Atlas who has two sub-branches, Deform Atlas, Landmark Selection on Atlas, Display Atlas Slices on Zoom and finally Display Atlas-Frontal Slice Matching.

Atlas Display is used to display Atlas Overlays on the entire right hand side of the screen. To equip the user with the ability of selection of vision of deformed and original atlas overlays a sub branch Original is added to the system. Further, to see deformed Atlas overlay on screen Deformed sub branch is to be preferred.

As it has been said in the introduction part, one of the main goals of the work is to integrate Atlas .overlays with CT images. Since the only useful overlays can be utilized for this purpose are frontal ones, determination of a certain way of placement of them to their correct places constitutes one of the most important philosophical process. The sagittal overlays make the placement of them onto sagittal CT views a must. The placement of them is to be done respect to two points of brain, Anterior and Posterior Commissure. Unfortunately, the zooming ability with the different zooming factors causes a problem. When the user decides to place frontal overlays to zoomed sagittal view with a zooming factor 2 and when he decides to place them onto a view with a factor of 4, a problematic case can easily occur during placement. In other words the way must be such one that the placement of sagittal overlays must be "zoom factor independent". Successful handling this problematic case is one of most powerful property of ACTR.

Figure 4.10 and 4.11 show two cases. In the case shown in Figure 4.10 the placement of frontal overlays on sagittal AC-PC plane on a CT image with a zooming factor of 2. On the other hand, for the case displayed in 4.11 the zooming factor is 4. As it can be inferred from the comparison of two figures, placement is zooming factor independent.

The details of the placement will be explained in "A Sample Registration" part and the functions of Atlas menu will be clear for the reader as he/she goes along.

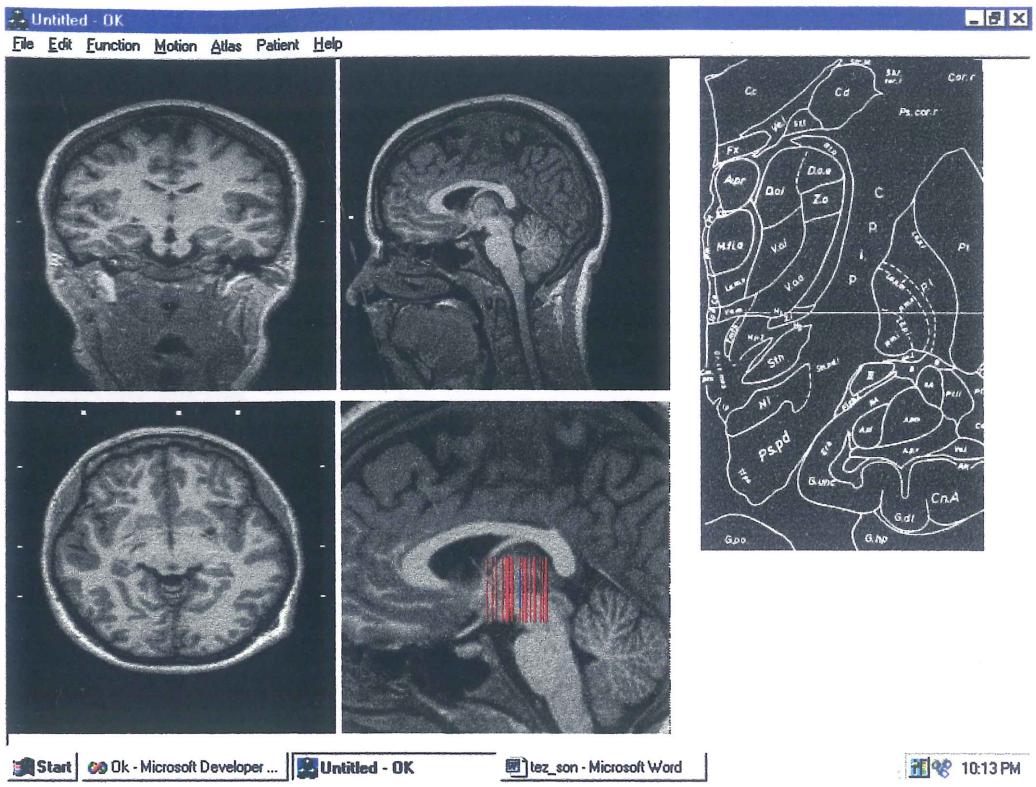

Figure 4.10 The case with zooming factor of 2 with red lines showing the places of frontal atlas overlays placed on sagittal CT image.

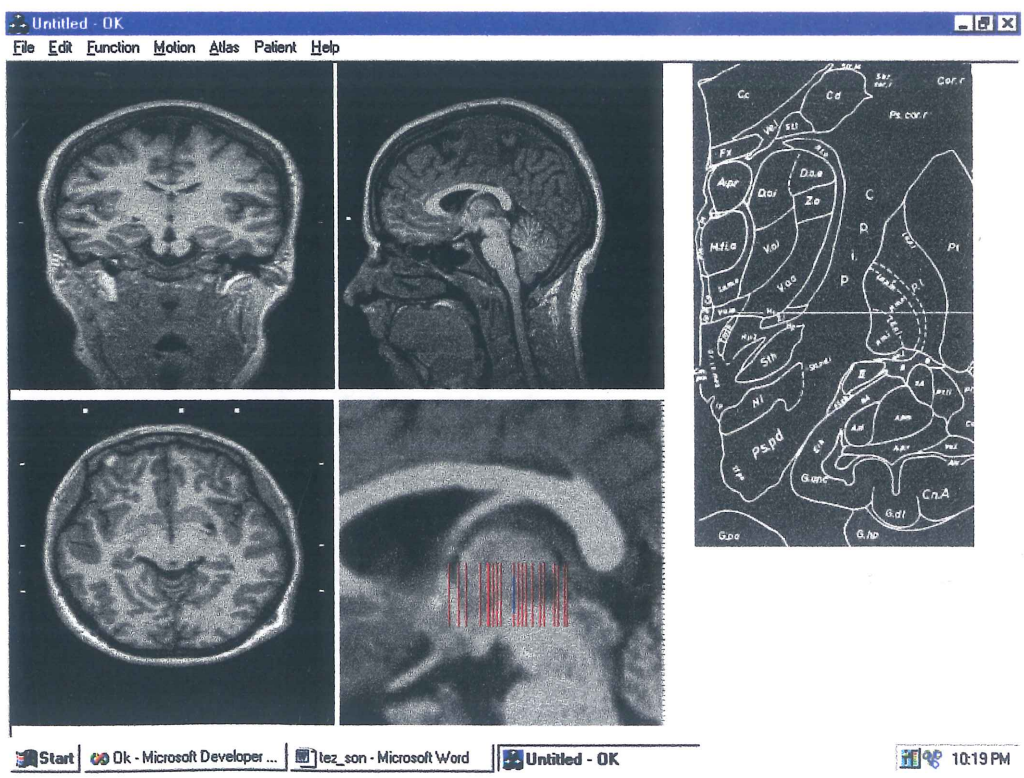

Figure 4.11 The case with zooming factor of 4 with red lines showing the places of frontal atlas overlays placed on sagittal CT image.

IV.1.2.4 Patient Menu

The installation of this menu is to provide the user with an automatic way to load axial slices of a patient quickly having the ability of choosing any one of patients from a list. General view of the menu is shown in Figure 4.12.

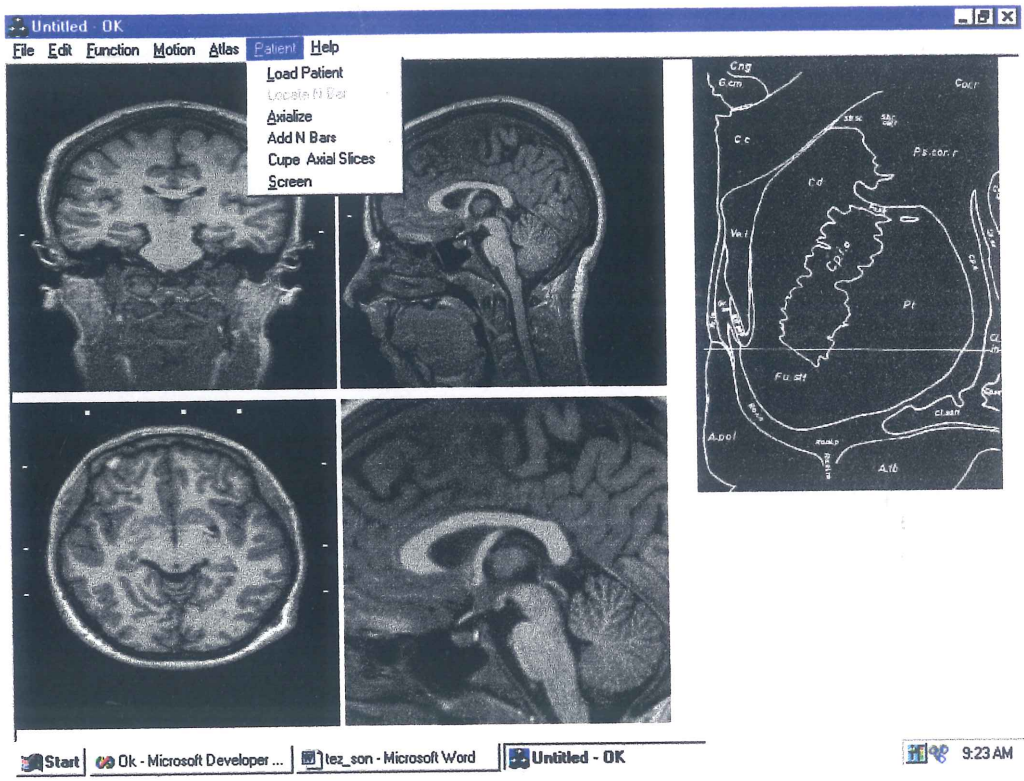

Figure 4.12 General view of Patient menu is open.

Load Patient item of the list opens an Open File Dialog box (modeless one (the type of dialog box which avoids subsequent actions on windows is not allowed unless it is either used or terminated) is chosen for the purpose to avoid possible problems) whose name is Patient Slices Selection with a default folder Patient. As it can be guessed its function to ease slices of a patient slices. For the time being the system is designed to load axial slices but to add loading other type of slices, namely, sagittal and frontal ones is a possible future work. Figure 4.13 shows the status of the interface when Load Patient is activated.

The functions of Axialize, Add N Bars, Cube Axial Slices can be handled together. In a case where the slices are provided in sagittal ones packed in a single file, Axilize is operated. Then to add n bar points, and to have them packed in a cube of axial slices is achieved with this sequence.

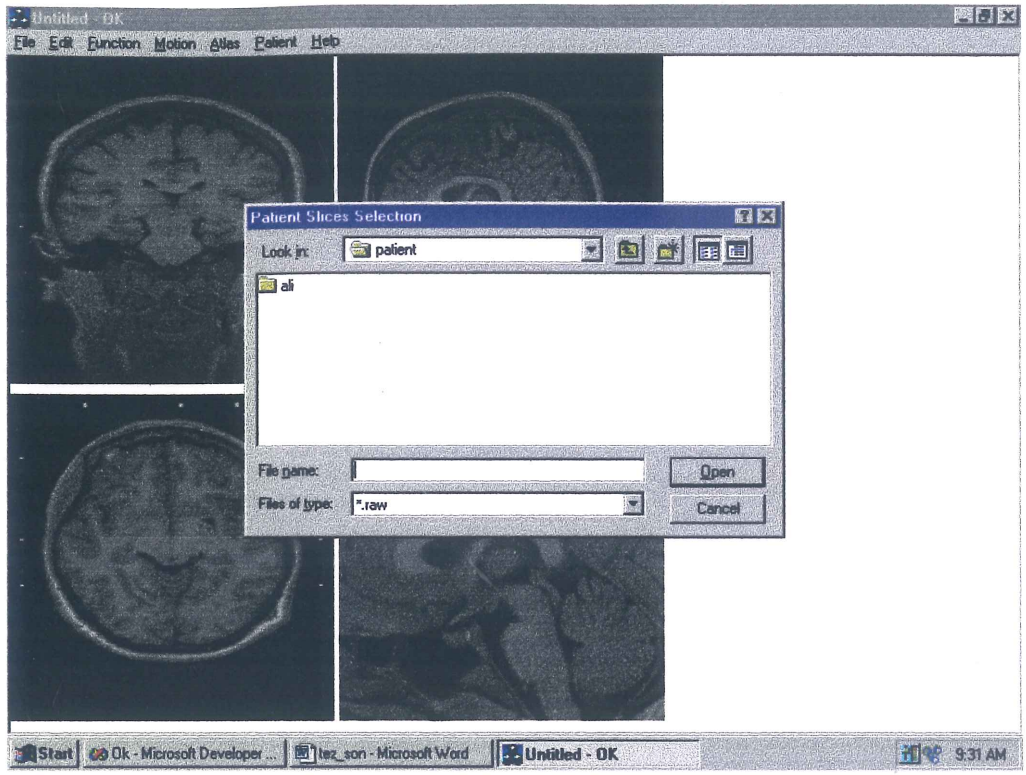

Figure 4.13 The apperance of screen when Load Patient menu item is active. The color of title of the interface is turned to gray and that of Patient Slices Selection window is blue, indicating that Patient Slices Selection window is a modeless one.

The function of the Screen button is to be clarified in the next section.

IV.2 A Sample Application by ACTR

The application starts with the interface in Figure 4.14. The activation of client area by clicking on Screen button of Patient Menu results in the placement of sagittal, axial, frontal slices with their default values. However the zoom is gray because the default zoom view is defined for this stage. This status is displayed in Figure 4.15

The first step is the rationalization of pixels. For the correct calculation of the position of a particular point, region in brain, the pixel-length rationalization is a must. This rationalization process has the following steps. A proper appearance of N bars is important, so the user should convert Figure 4.15 into Figure 4.16 to be able to obtain all rationalizations for all three directions, sagittal, frontal, and axial. The user should click on top and bottom of N Bar in the sagittal view to perform axial pixel-length rationalization. Each click leaves red crosses, which are thought as a visional check. Figure 4.17 shows the status.

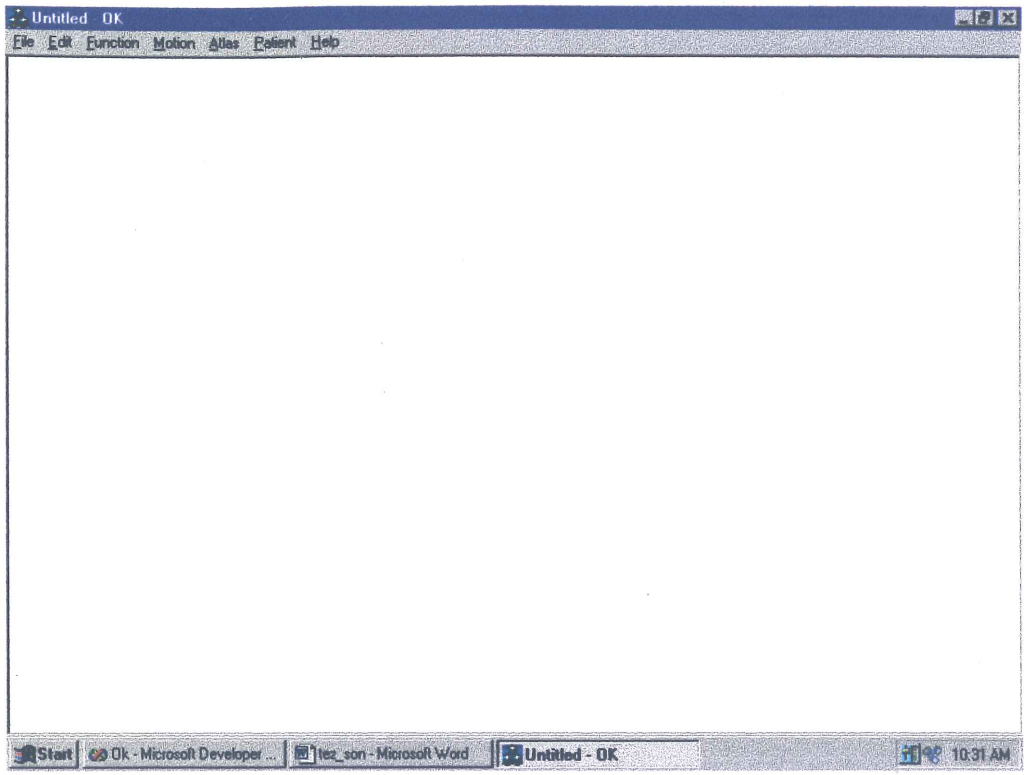

Figure 4.14 Appearance of Screen in the beginning.

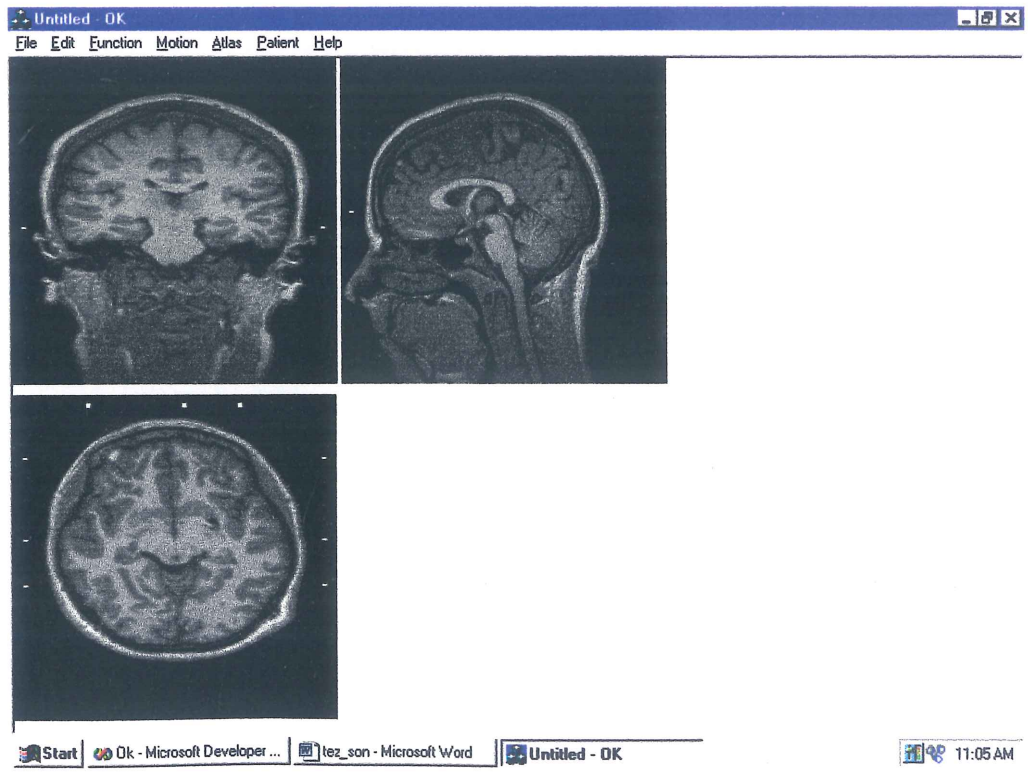

Figure 4.15 After Screen button of Patient is clicked on.

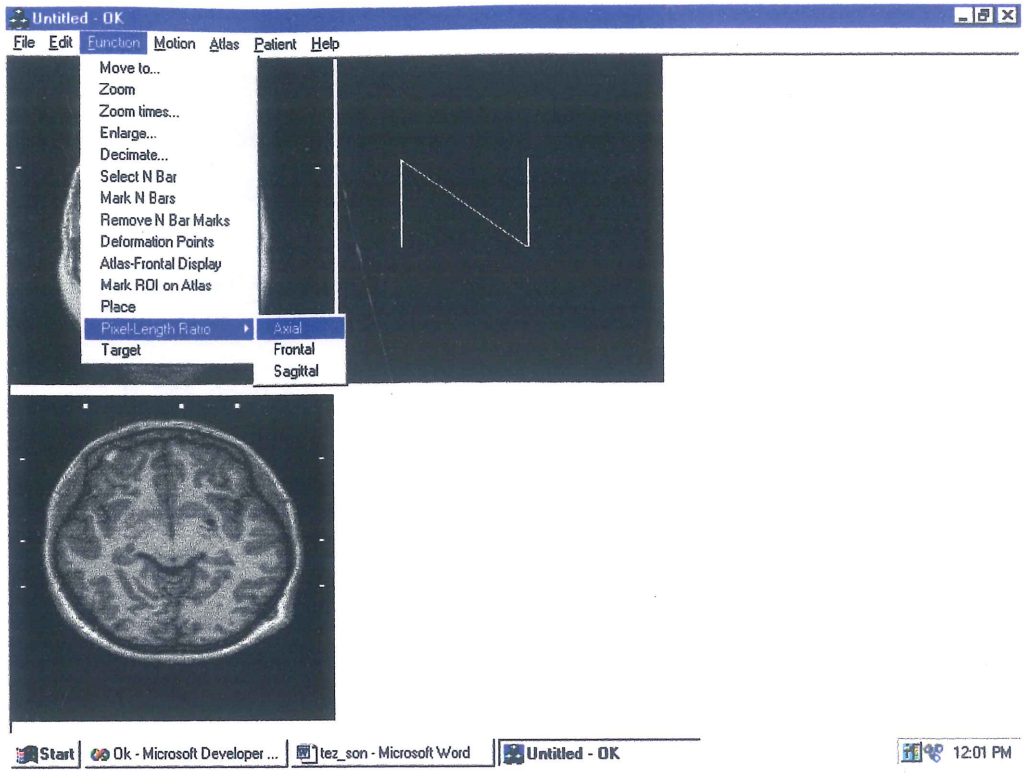

Figure 4.16 The Pixel-Length Ratio is utilized.

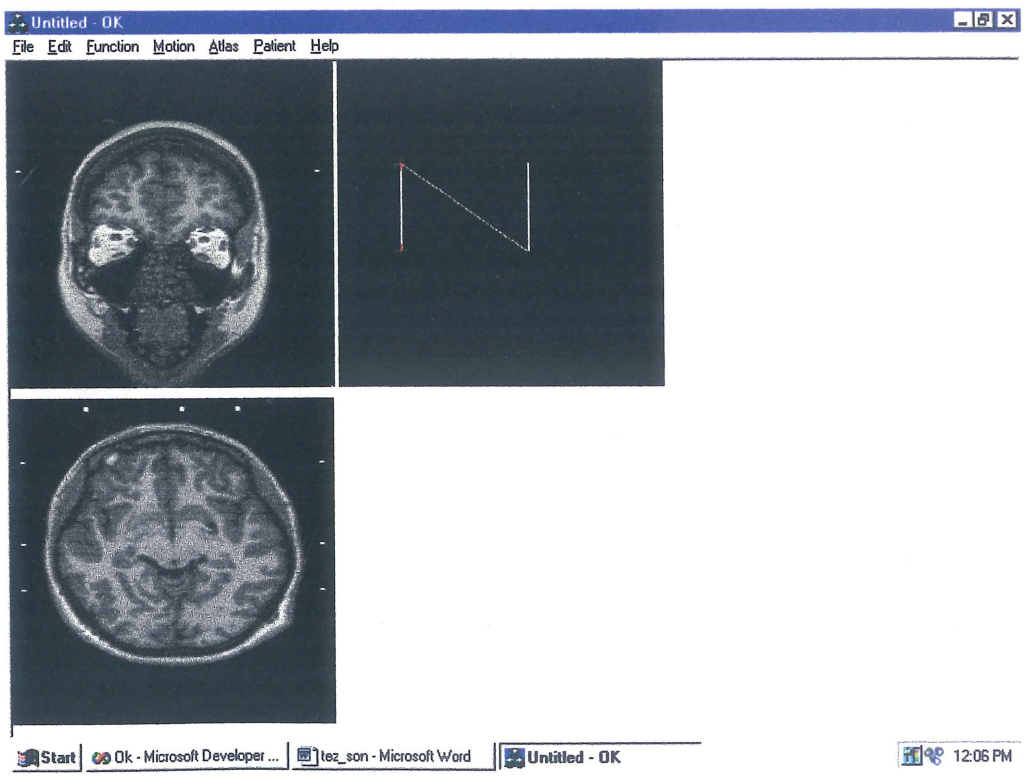

Figure 4.17 Red-Crosses on N Bar on sagittal slice for pixel rationalization

The application of axial pixel-length is explained explicitly. For the remaining cases the user should click on the spots of N Bars in axial view. To get frontal rationalization N bar spots in axial in the vertical direction should be used, whereas the horizontal one is to be preferred for the sagittal process.

What follows is the determination and display of the slice, which includes the AC and PC: Since all of slices can have a slice with such a property, a preference is to be following. As it has been stated in context the only available Atlas overlays are frontal ones, and their places are given respect to the positions of AC and PC and bisection of AC-PC line. The other fact also becomes the most important criteria due to information above: AC and PC are seen the most clearly on sagittal CT views. Therefore the zoomed view must be adjusted in such a way that it displays a zoomed view of a sagittal CT slice comprising AC and PC. To achieve this the user can use "Move to..." function to move the current sagittal slice close to one, which is a good candidate to satisfy the above criterion explained in the previous sentence. Roughly such a slice resides on the bisector of axial line. Figure 4.18 shows a case where a sagittal view with AC and PC points and its two fold zoom is also placed in zooming part of the ACTR.

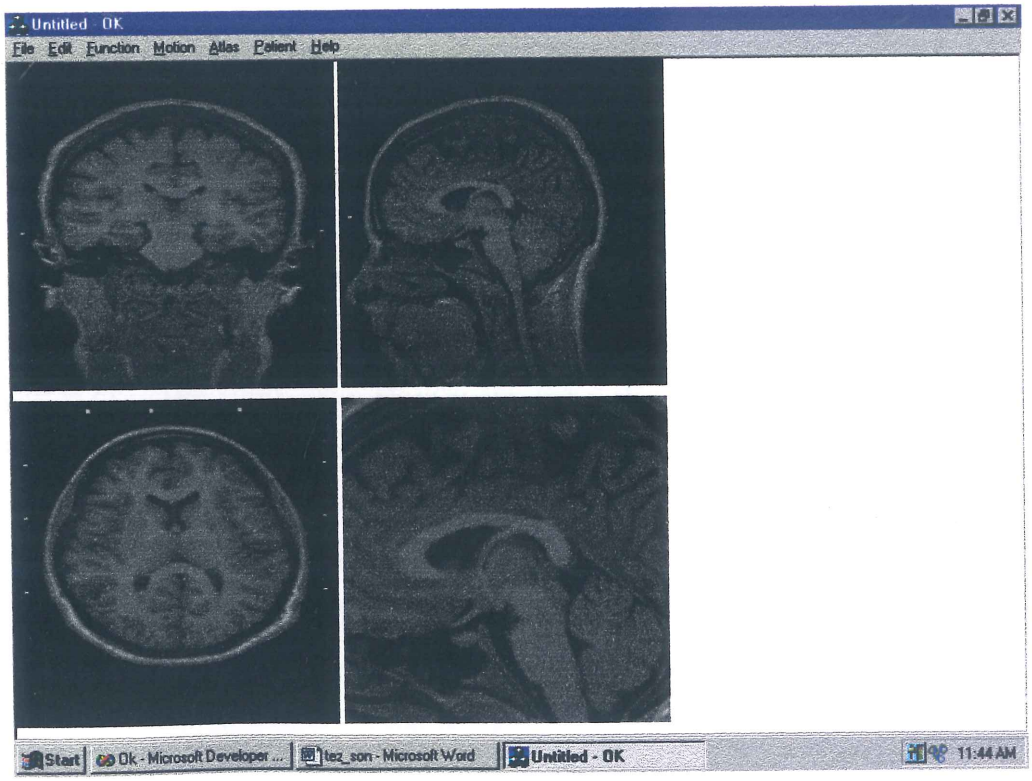

Figure 4.18 The case where the sagittal slice with AC-PC line and its zoom.

Placement of atlas overlays on sagittal CT zoom is achieved by "Atlas Menu". By clicking on AC and PC after choosing Landmark Selection on Zoom yields in the scene in Figure 4.19. Green crosses indicate the positions of AC and PC. The next menu is Display Atlas Slices on Zoom. The result of this selection is demonstrated in Figure 4.20.

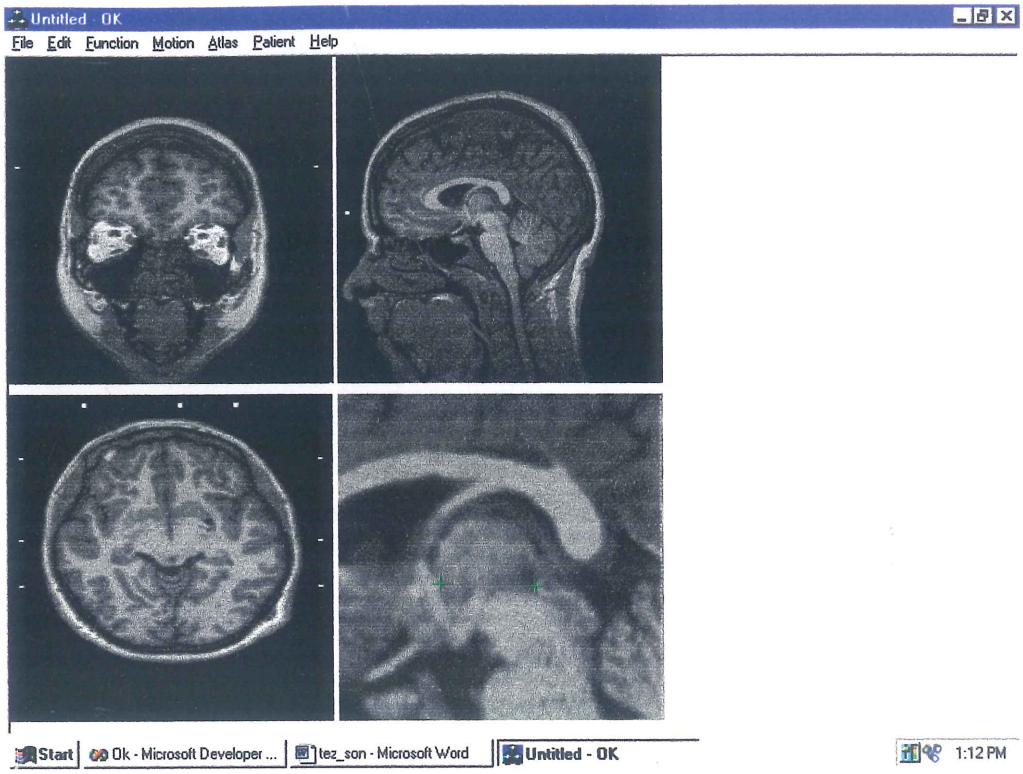

Figure 4.19 Green crosses indicate places of AC (left) and PC (right).

Placement process is complete now. However, a correlation between the frontal view and these atlas overlays is an obligation, because there are frontal atlas overlays available and a matching between an overlay and its frontal view is the only alternative to register the overlay. Hence, Display atlas-frontal slice matching button selection yields the appearance in Figure 4.21. The short, blue vertical the place of frontal slice shown in frontal view portion left upper region of the screen. As it is mentioned the longer, red vertical lines correspond the places of atlas overlays. Actually, the black color of Atlas portion, entire right hand side, means there is no coincidence between current frontal view and atlas view. :If such a coincidence occurs, the atlas region will display the atlas overlay. To get such a result the user can refer to Motion menu to click on Forward on Frontal Atlas of Atlas-Frontal Slice menu option such a result is obtained. Figure 4.22 and Figure 4.23.

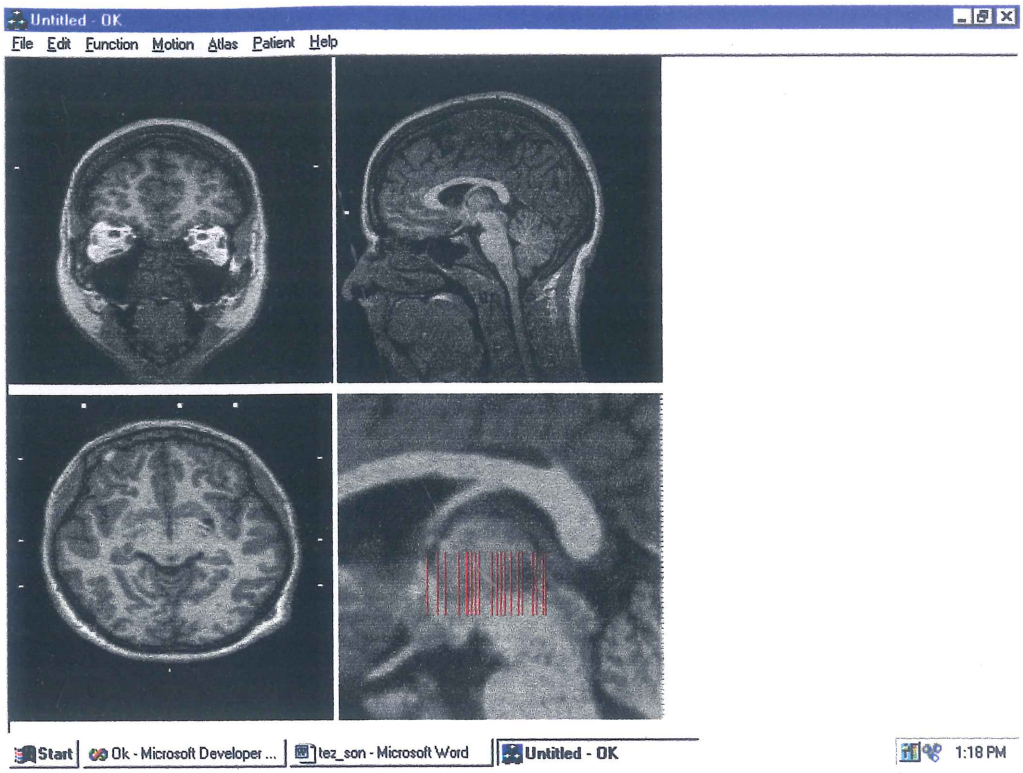

Figure 4.20 Red vertical lines the places of Atlas Slices.

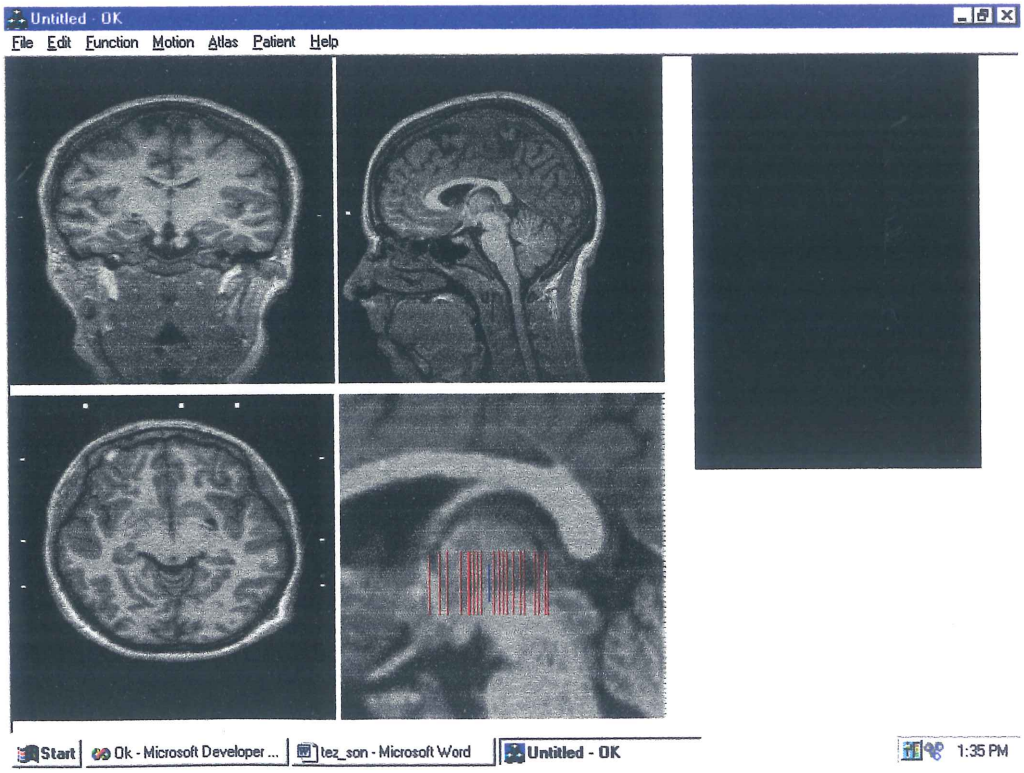

Figure 4.21 Atlas overlays are shown by red lines and the blue is for sagittal view.

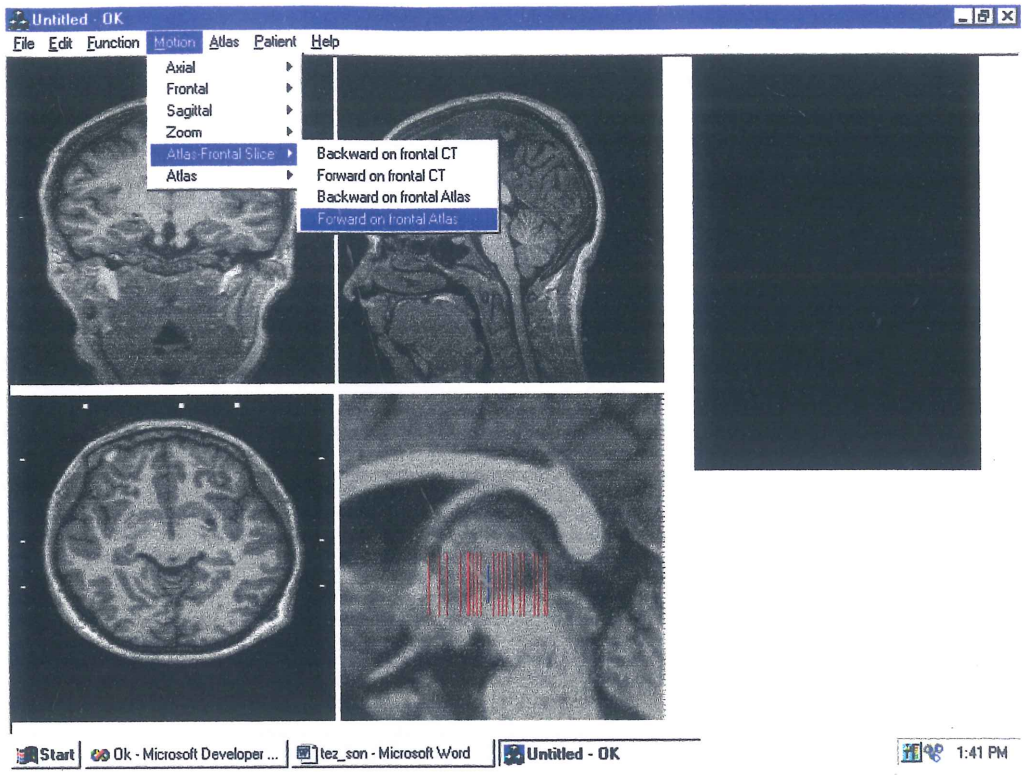

Figure 4.22 Forward on Frontal Atlas is chosen.

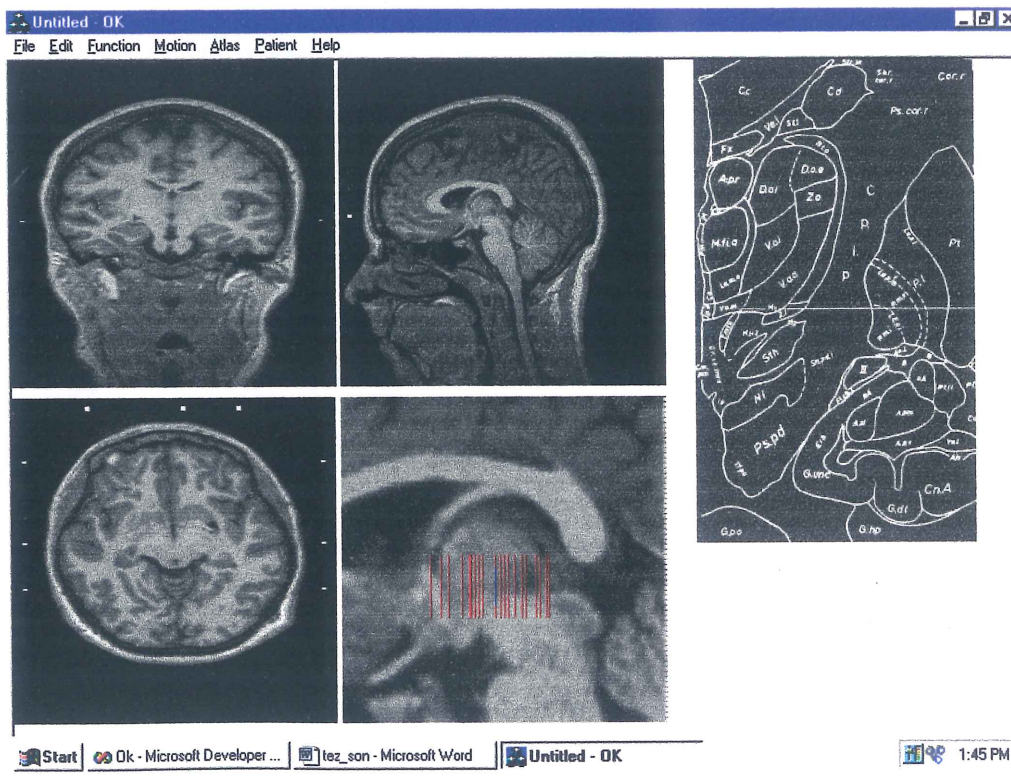

Figure 4.23 Coincidence of red and blue lines result in the display of atlas overlay.

There is to be matching between the frontal atlas overlay and frontal CT slice. The processes told up to now already do such a matching. To register atlas overlay with frontal CT slice some analog points between them should be chosen. Though, such a selection could be done from frontal view part (upper left part) and the atlas, a better situation would be a selection done between a zoomed frontal view and the atlas. So, the implementation of a step has been added to the work. It is invoked by Atlas-Frontal Display selection on Function menu (Figure 4.24).

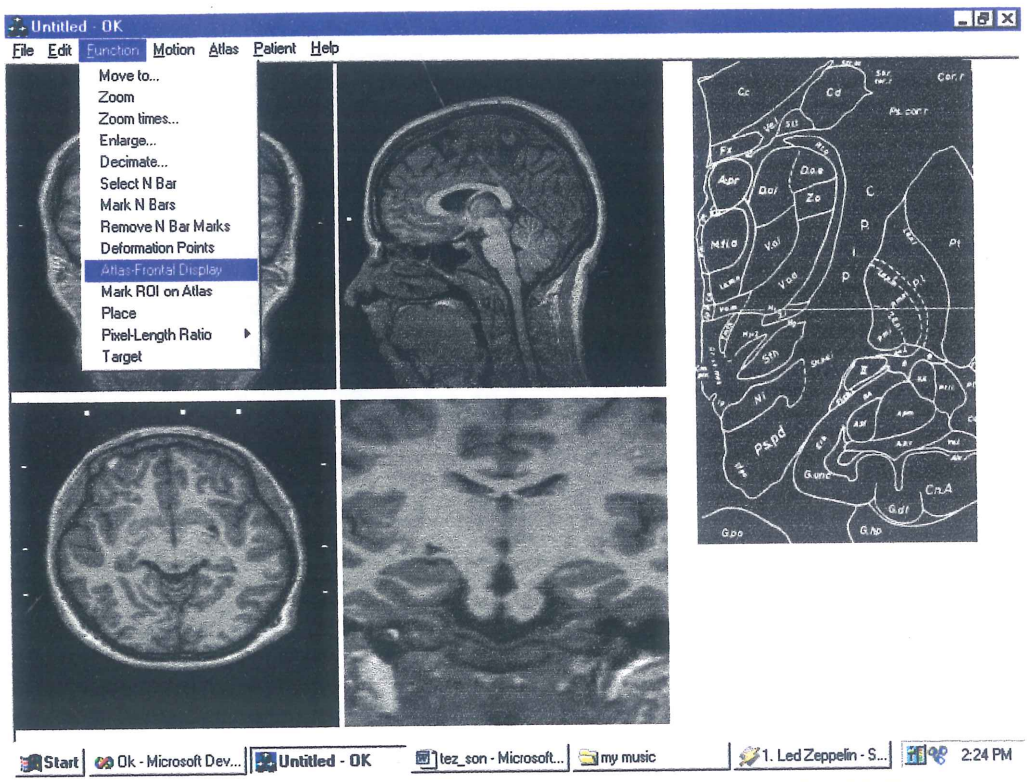

Figure 4.24 To get zoomed frontal view of atlas slice the user should click on.

Hence, this action turns the three display sides, frontal CT view, zoom view and atlas vies show the same slice with different appearances: Frontal CT view shows the frontal CT, zoom part displays its 2 fold zoom and finally atlas part shows the corresponding atlas overlay Figure 4.25.

ACTR now requires the user to point analog points from zoom part and atlas overlay. To have a better selection with less error, the user can increase zooming factor to 4 or 5. Spanning abilities can be utilized to zoom more properly. This situation is shown in Figure 4.26.

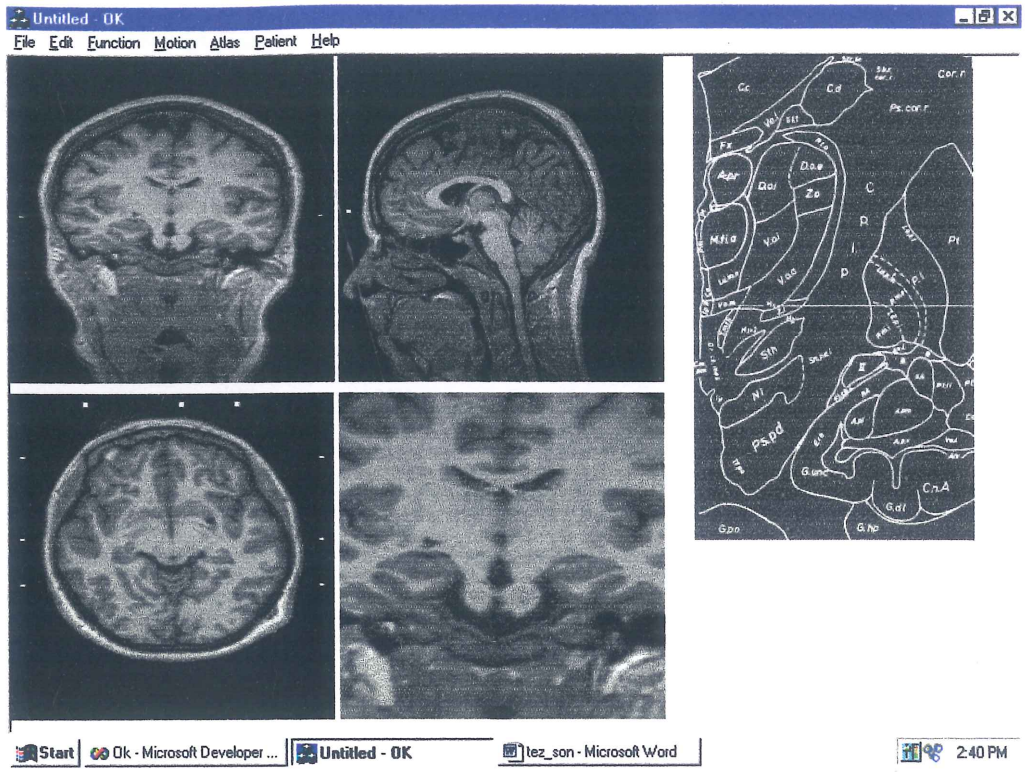

Figure 4.25 Case where sagittal CT view, zoom view and atlas view are the same.

At this point deformation process starts. First step is to mark a region of interest on the atlas overlay. The Mark ROI button is designed for this purpose. The user should click on Mark ROI and should click on the borders of ROI. Clicking on the same button for the second time results in the status shown in Figure 4.27.

Deformation process continues with the following steps. The user this time must determine analog pairs between the zoomed frontal CT image and atlas overlay. To do so, Deformation Points button of Function Menu is to be utilized. The clink on that button makes system ready for entering coordinates of analog points [22]. The user must click in a definite order. The user must for point from zoom part. Then he/she has to click the analog point of the one he/she has chosen from zoom part. Shortly, he/she should points in this order: one point from zoom part and its analog from atlas overlay with the help of left button of mouse. Since for each of point selected from zoom part there is an analog of it on sagittal overlay the total number of chosen points must be an even. Figure 4.28 is an example of this case. It contains 8 points on zoomed sagittal CT image and their analogs on the overlay. Small, red crosses on the screen indicate the points.

One of most powerful facilities of ACTR is hidden in the paragraph above. The zoom factor has never been mentioned above, because ACTR is designed in such a way that the calculations of deformation yield in correct results independent of zooming factor. This property gives the user more freedom, and makes ACTR have a broader field of application starting from the ones with a small zooming factor to the ones with a larger zooming factor.

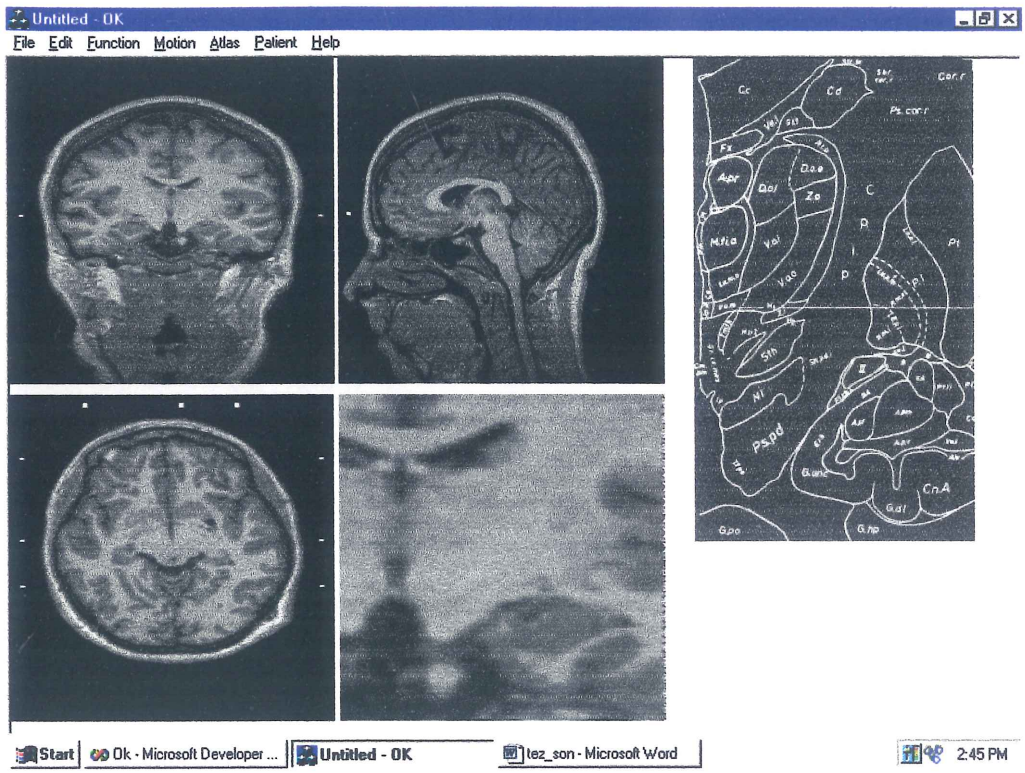

Figure 4.26 An example of spanning ability of ACTR.

Now the final step for deformation process comes. ACTR deforms the atlas overlay by a click on Deform menu option of Atlas Menu. The result is not obvious at first. The only change compared to the case shown in Figure 4.28 is removal of the deformations points. If the user continues the process with a click on Deformed option of Display Atlas menu item of Atlas Menu the situation changes into the one shown in Figure 4.29. The screen has the deformed atlas overlay placed on the entire right hand side of the screen. Figure 4.29.

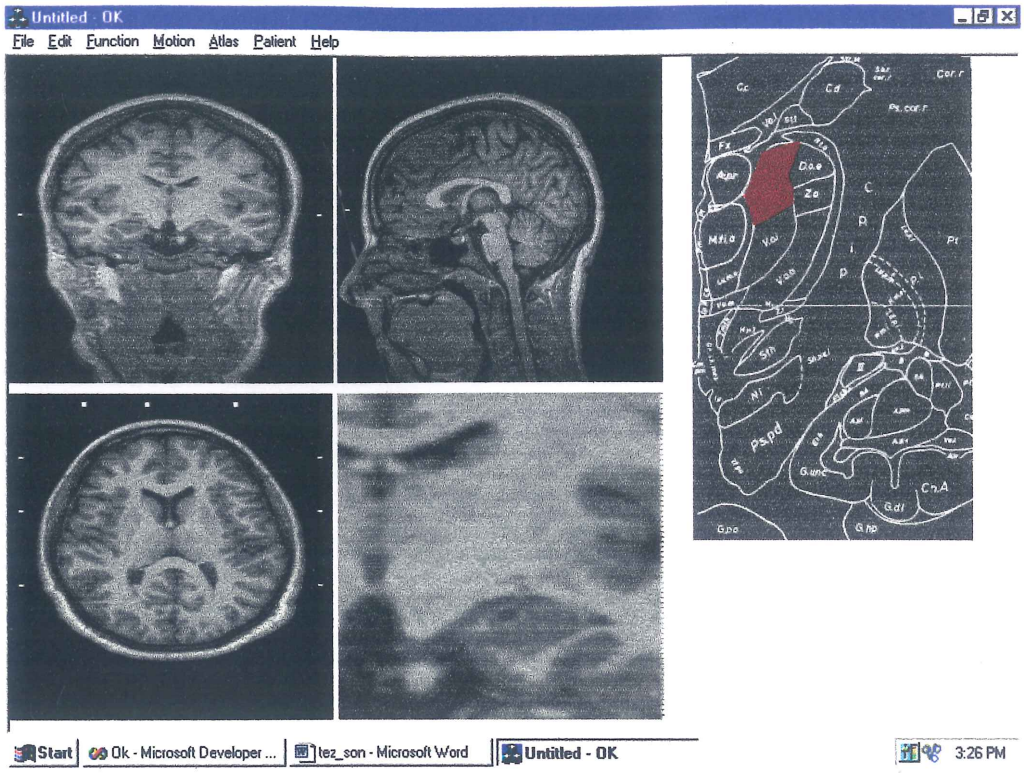

Figure 4.27 ROI (Region of interest) Selection.

The main goal of the sample is the determination of this ROI respect to a predefined origin in the system. The origin is the left down corner of the axial slice. The coordinates are calculated respect to that point. Horizontal line is x direction and vertical line starting from the origin constitutes y direction. All coordinate calculation is to be done respect to this basis. Y coordinate is the easiest one to handle, because the number frontal slice gives the y direction with the multiplication of it with frontal pixel-length ratio. Z dimension is obtained by calculation of the number axial slice with axial pixel-length ratio but with some correction factors due to zooming. For X dimension the case is similar to Y dimension calculation. Since there is an effect of zooming in X dimension some correction factors are added to code. The number of sagittal slice factored by sagittal-pixel length ratio calculates X dimension. Hence another important property of ACTR is here. Again, the zooming ability does not affect the calculation of any of x, y or z dimension.

The sequence requires the user to place the deformed the atlas overlay on its proper place. This requirement is achieved by a function with a function whose name is same with the process: Place. It is under Function Menu. The status of the screen becomes like the one in Figure 4.30.

The sequence ends with the targeting process. The user can determine the coordinates of the target simply clicking on any part the ROI after the activation of Target function of Function Menu. The case is shown in Figure 4.31. There is a red cross with a lighter tone respect red background. The cross the point whose coordinates is to be calculated. A second click on Target button shows the coordinates of the point displaying it on a message box Figure 4.32.

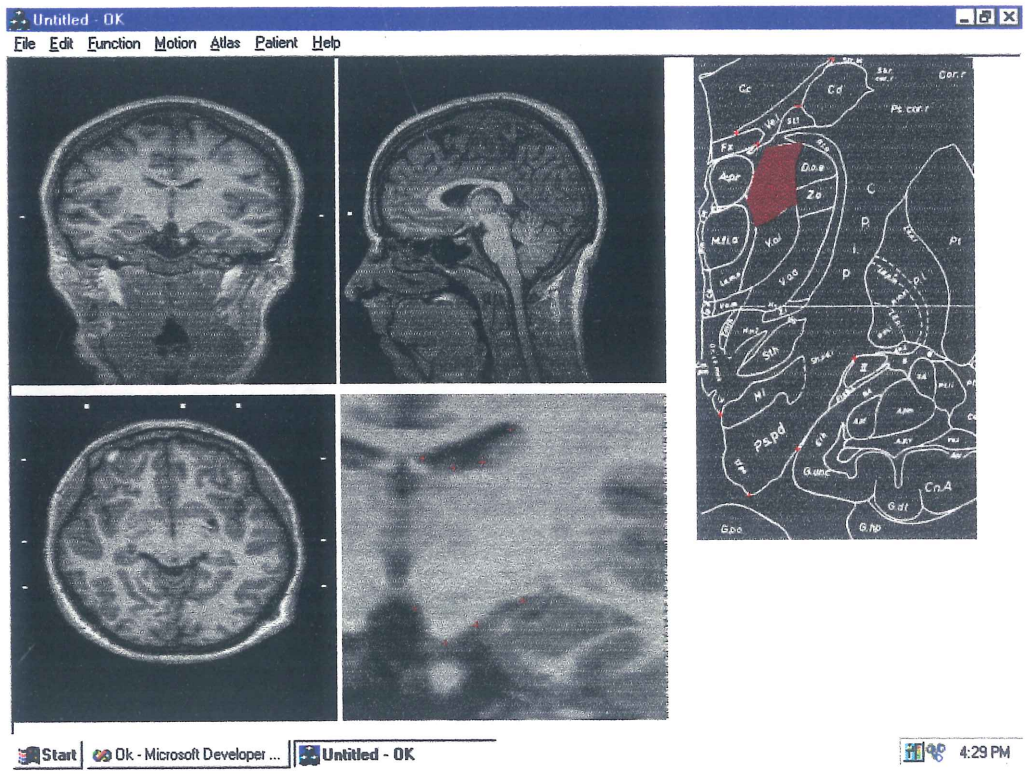

Figure 4.28 Deformation Points on CT and Atlas images with ROI.

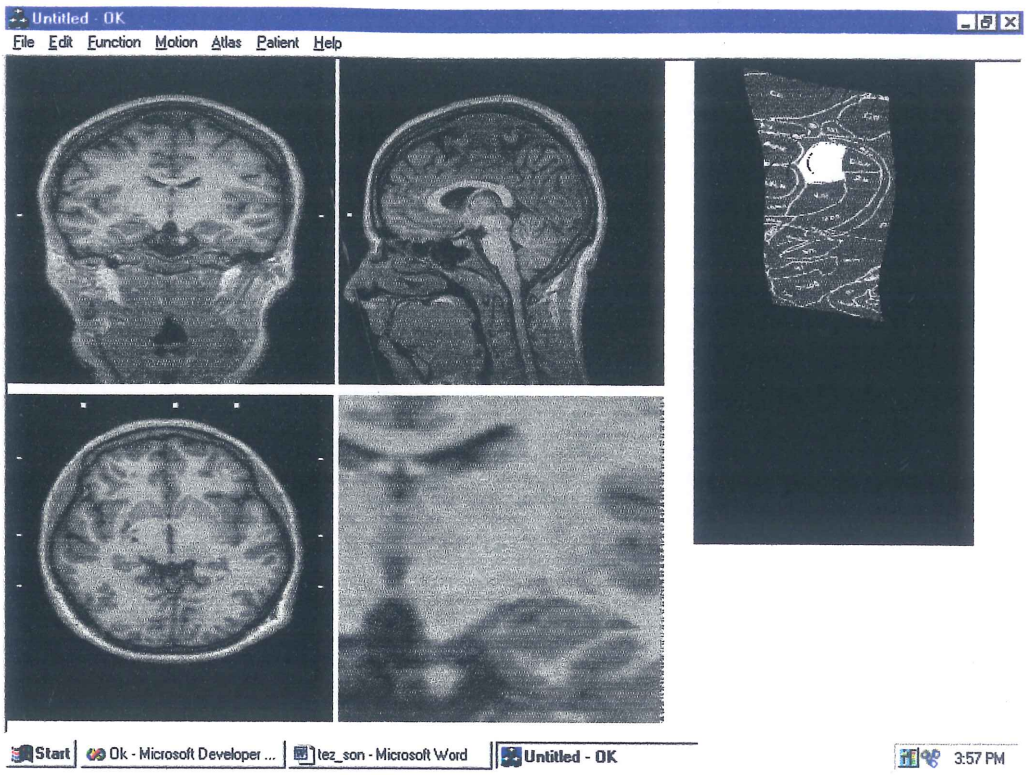

Figure 4.29 Deformed atlas overlay on the entire right side.

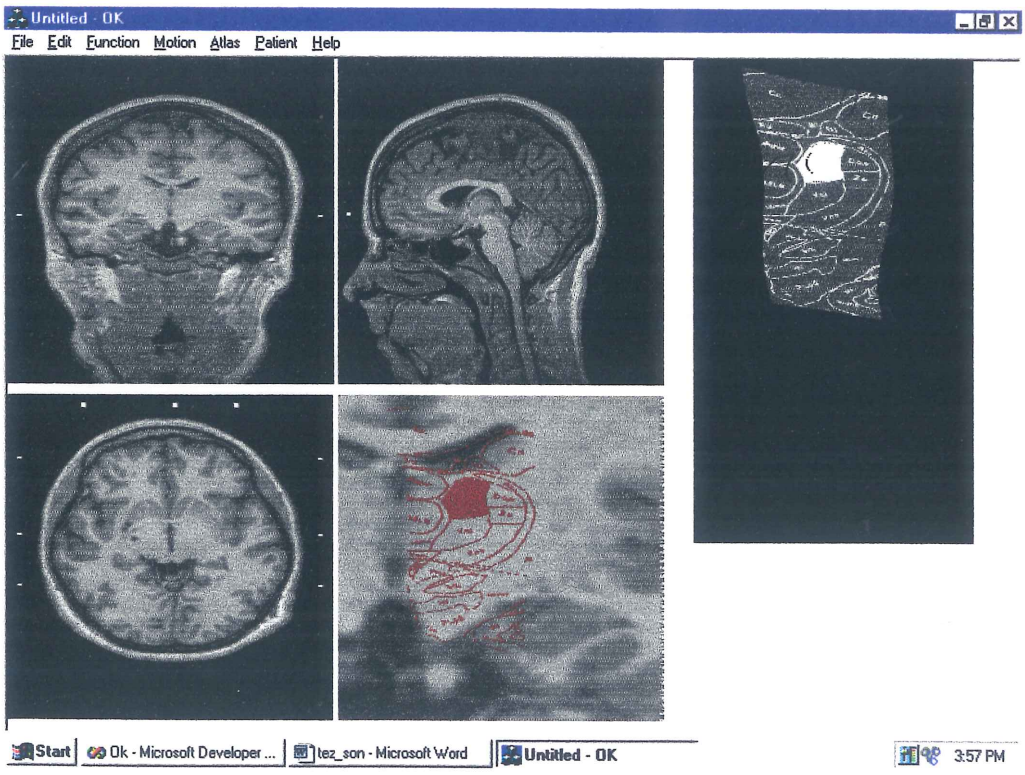

Figure 4.30 Deformed Atlas overlay on its proper place on zoom part.

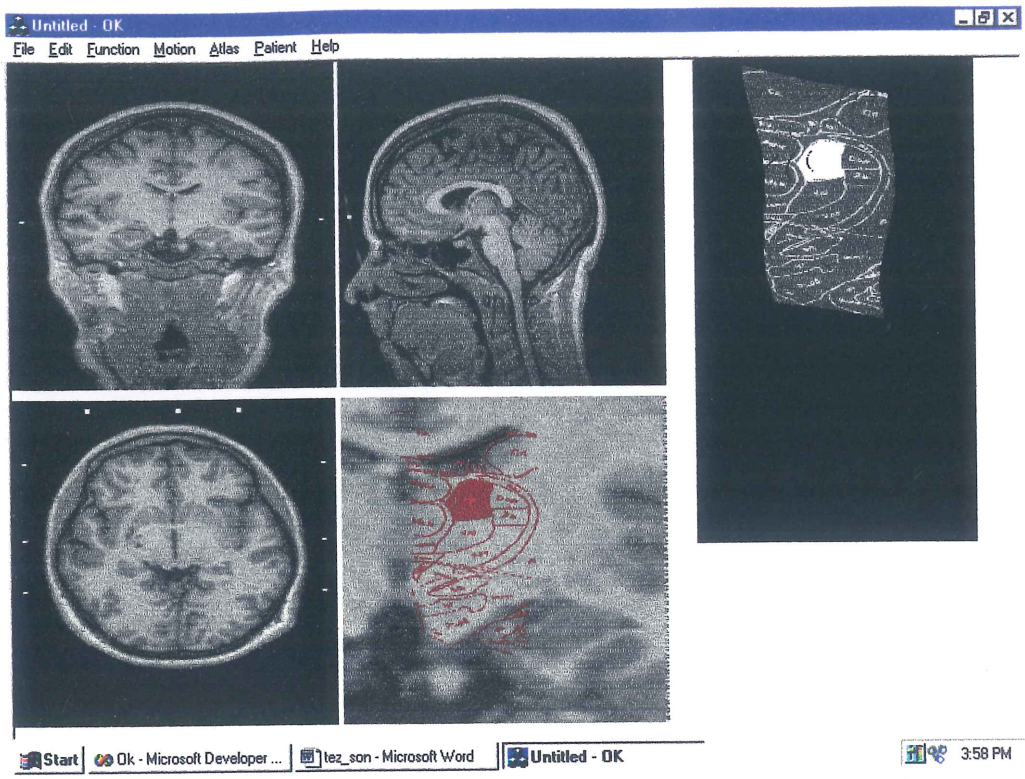

Figure 4.31 First step of Targeting process leaves a lighter dot on red ROI on zoomed part.

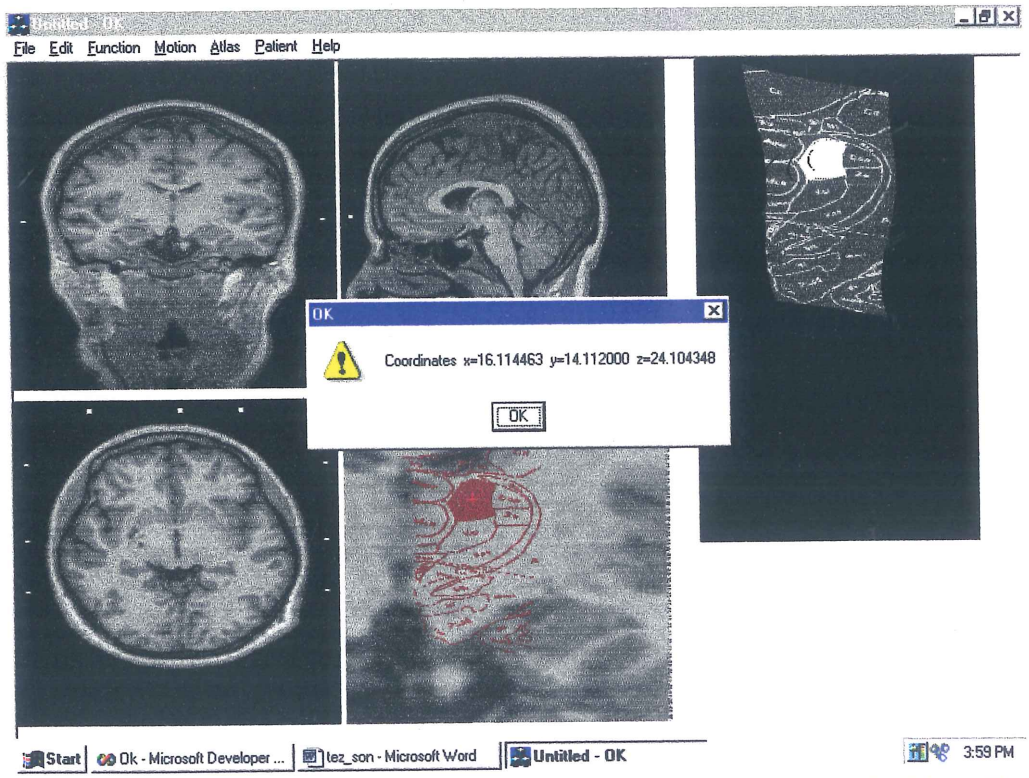

Figure 4.32 The calculation of coordinates of the target is shown after a second click on Target function of Function.

The sequence ends with the targeting process. The user can determine the coordinates of the target simply clicking on any part the ROI after the activation of Target function of Function Menu. The case is shown in Figure 4.31. There is a red cross with a lighter tone respect red background. The cross the point whose coordinates is to be calculated. A second click on Target button shows the coordinates of the point displaying it on a message box Figure 4.32.

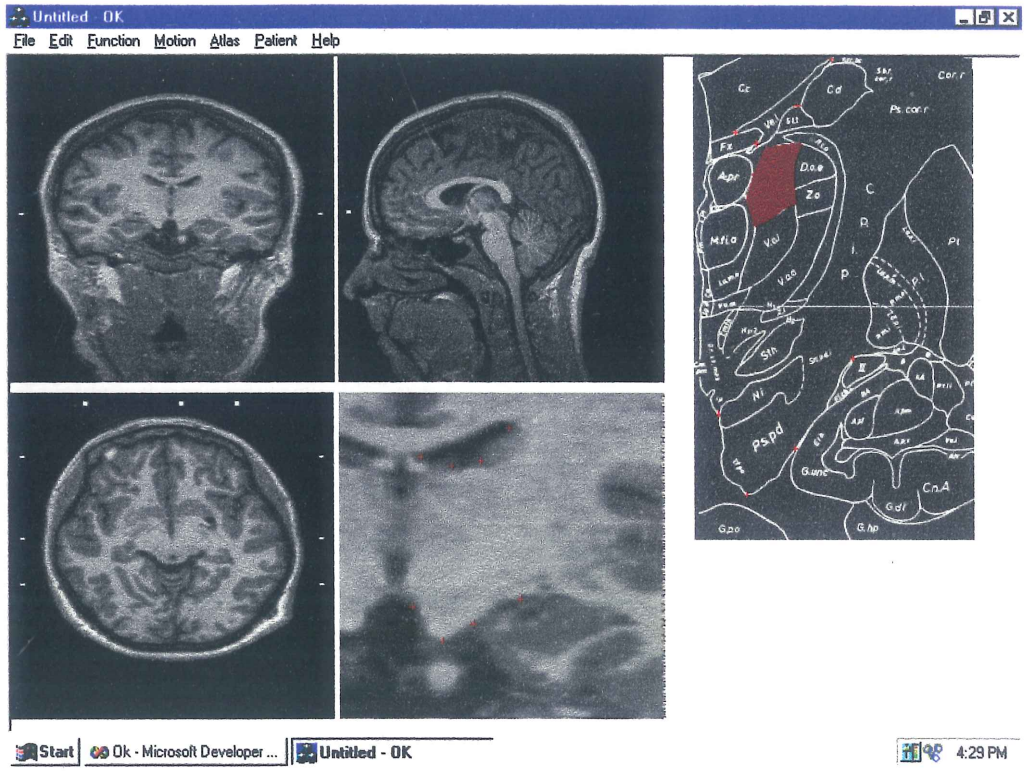

Figure 4.28 Deformation Points on CT and Atlas images with ROI.

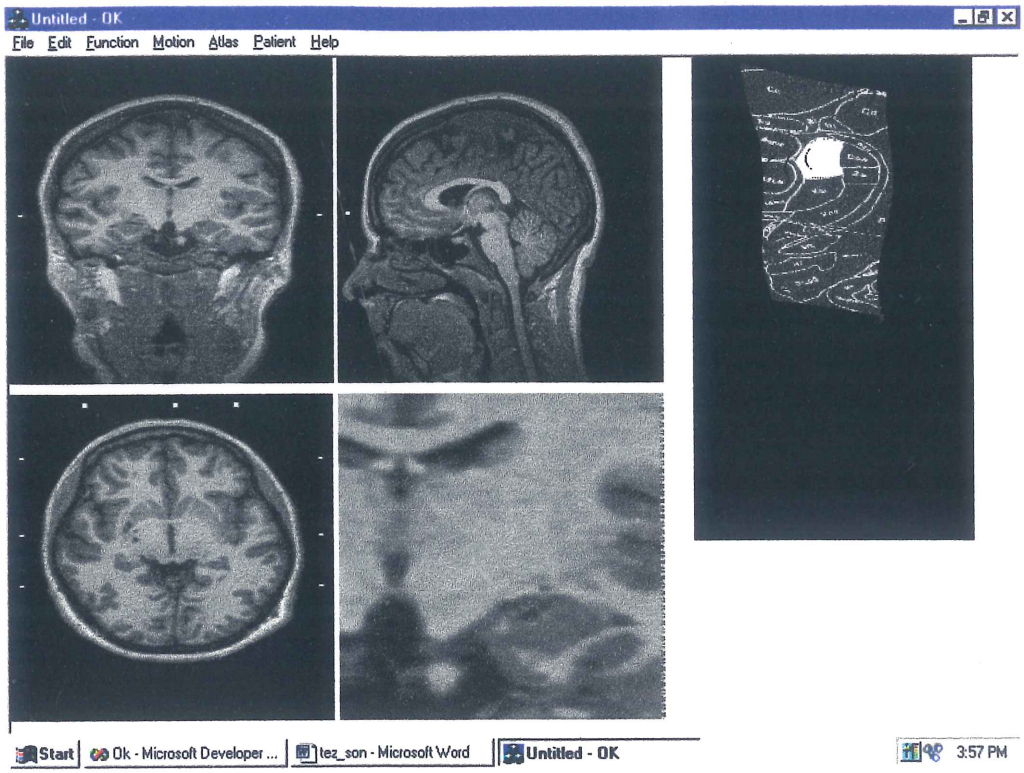

Figure 4.29 Deformed atlas overlay on the entire right side.

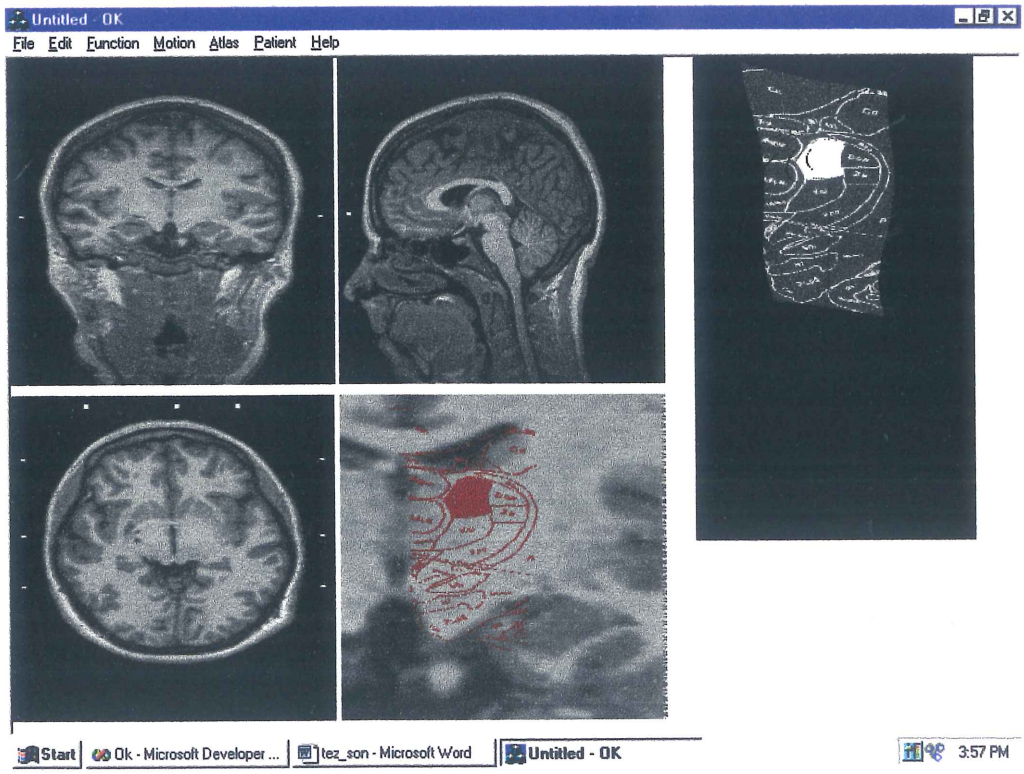

Figure 4.30 Deformed Atlas overlay on its proper place on zoom part.

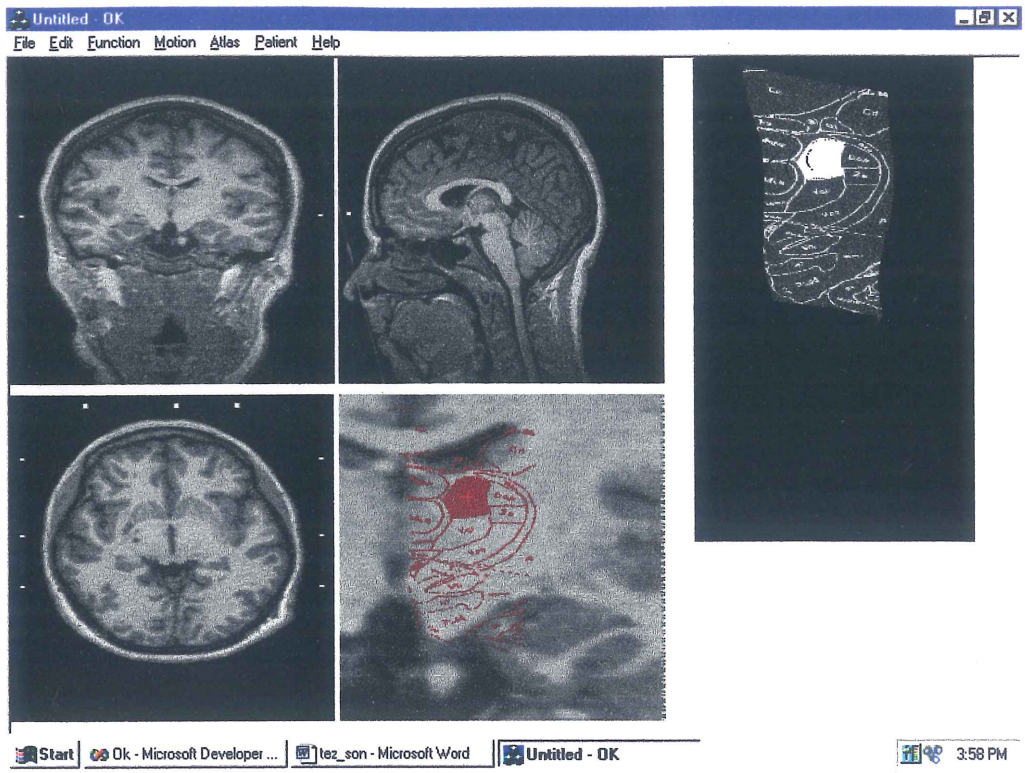

Figure 4.31 First step of Targeting process leaves a lighter dot on red ROI on zoomed part.

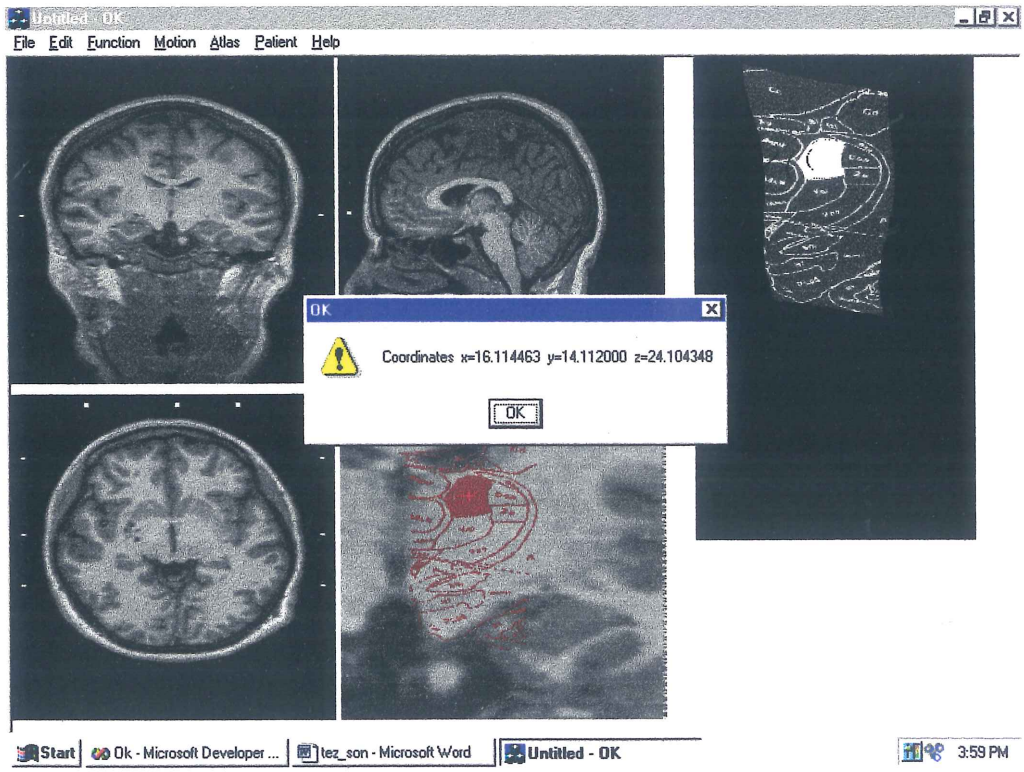

Figure 4.32 The calculation of coordinates of the target is shown after a second click on Target function of Function.

V. RESULTS AND DISCUSSION

CT and MR are two modalities used worldwide. As well as for imaging for diagnostic purposes, they are used for pre operational target determination purpose. As mentioned in the introduction, they are sometimes not available for this purpose. Another entities, Brain Atlas Slices, play important roles during pre operational target determination sessions because they provide the most detailed views of brain. Unfortunately, there is an obstacle about them; they are acquired from a certain person, in other words they are static images, namely photographs of brain of a healthy person. Atlas slices, CT and MRI are three distinct entities with a great potential for pre operational target determination.

In this work a tool named Atlas CT Registrar is constructed. The main goal of the tool is to provide the surgeon with a method so as to integrate atlas slices with CT or MR images. The tool serves as a good medium for this purpose. Furthermore, it enables the selection of slices, and with the different functions placed in menus; it results in motion through slices.

Another property of the ACTR is the deformation of atlas slices so as to make them fit to a certain subject's anatomy. Since the atlas slices belong to a certain person, they do not give enough information to be exploited for preoperational aims. By feeding a deformation algorithm atlas is deformed to fit the subject's anatomy.

For future work, the integration of CT and MR slices with the same kind of tool as ACTR is going to be a good target. The achievement of such an aim is going to extend the information for pre-operational target localization by providing the user with both detailed images of the region by means of MRI, and with the images acquired by CT.

The main result of the work to be mentioned is its usage in preoperational target determination so as to help the neurosurgeon who wishes to have a more "specified" operation with minimum number of insertions into a subject's brain and with less effort he/she has to pay during an operation.

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