

# INTERNSHIP REPORT

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**2nd year internship: Discovering the research environment.**

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**Internship period:**

June 24th to September 2nd 2013

**Subject:**

3D images processing - application to paleoanthropology:

- Develop a watermarking software for 3D images.
- Try to find tools to help image segmentation.



## Introduction

In every French engineering school, it is compulsory to do some internship to practice what you learn during your scholarship. The conditions of these periods in companies or research laboratories depend on the schools. At Ensimag, a school where students are taught computer sciences and applied mathematics, the first internship has to be at the end of the 2nd year, and has to last about 2 months.

In this school I chose the branch Graphics and Mathematical Modeling because I always wanted to work in the medical imagery field, and this is the best way to achieve my goal. I also wanted to do my internship abroad for two reasons: to improve my skills in English and to discover a new culture for working. That is why I decided to look for an internship that could gather these two aspects.

I did my internship at the university of Witwatersrand of Johannesburg in South Africa. My tutor, Gerard Subsol, a researcher for CNRS who works in LIRMM in Montpellier has indeed some colleagues of the paleosciences department of this university and he sent me in South Africa in order to work on several projects.

In this report I will begin by explaining the context of my internship, and all the non technical aspects of it. Then I will explain the different projects I have been working on, the objectives I had and my results. I will end this report with some conclusion and my personal feelings of this great experience.

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## I. Context

### 1. Host structure : the LIRMM and the University of Wits.

I worked for the LIRMM which is a French public Institute of computer sciences, microelectronics and robotics. Dr Subsol is permanent member of the ICAR team, a department of LIRMM which is specialized in Robotics and Computer sciences and applies its results to medical field or paleontology for example. Dr Subsol is a specialist of 3D deformable template in the medical and paleo-anthropology field. That is why I have been doing my internship in the paleosciences department in one of the biggest university in South Africa (and Africa).

I was in South Africa from June 24th to September 2nd at the university of Witwatersrand, also called Wits. This university is very well known for two main fields : the mines and the paleo-anthropology. I integrated the Institute of Human Evolution (IHE) and I worked with two doctors in paleo-anthropology : Kris Carlson and Lee Berger.

### 2. A brief introduction to paleo-anthropology

Paleoanthropology is the study of ancient humans as found in fossil hominid evidence. In the department of Wits there are researchers who work on human fossils but some others also work on dinosaur fossils, old reptiles and first mammals. However I only worked with researchers who are studying human fossils.

In South-Africa most of fossils are found in big pieces of rock. That allows a good conservation of the fossils but the problem is the extraction of the bone. Until the last decade, there were only two ways to process these blocks : either to extract it mechanically (with some hummers and dentists tools for example) or chemically. These two ways of extraction can heavily damage the bones and then raise problems for the post-study of the extracted bones.



*Example of a piece of rock that contains bones.*

With the advent of new technologies and new medical image machines (MRI, radiography) paleoanthropologists had the idea to scan the rocks in order to extract the bones digitally : they could after print them out with a 3D printer and study the bones without damaging the original ones. This is a very challenging problem for computer scientists because those kind of methods are very complex and difficult to apply on these blocks for several reasons. The main reason is the quality of the image : the rock is very dense and it is not very easy to scan a huge piece of rock, much harder than scan human being bodies.

I worked with the paleo-anthropologist Lee Berger who is quite known for having discovered a very important fossil in the human evolution called Australopithecus Sediba. Modern humans like us belong to the species "Homo" but everybody agrees that we have ancestors called "Australopithecus". The link between these two species is quite unknown until now, and this fossil Sediba, discovered in 2010 is very important because it shows similarities with both species, and could explain a bit more from where we come.

## II. Objectives

I got principally two goals for my internship : developing a watermarking software and trying to find preliminary results to segment some recognizable shapes in the images scan.

### 1. The watermarking software

#### A) What is it for ?

At Wits university researchers have installed a micro CT-scan in order to scan their fossils easily. A machine like this one works like a medical scanner but is much more powerful, which is really important to scan blocks of very dense rock.

The use of CT-scan images have raised the problems of copyrights of the images. One advantage of digital data is that you can copy and transfer them easily. But it can also be a problem : if you want to protect your data in order to restrict the access of them to only specific users it is quite difficult. You can never ensure that your data will not go on the Internet and everybody will have access. One of the solutions found by the scientific community to protect images is digital watermarking.

Watermarking or steganography is a very old idea which consists in hiding some messages in a invisible way in a media, with the aim that you cannot remove the message without damaging the media. It is the same principle with banknotes for example : if you look through a banknote you can see some images by transparency. If you are not aware that there is some images hidden you will never see it and you cannot remove these images without damaging the banknote. If you cannot see all the details through transparency then it means that the banknote is not the original one, in other words it is a fake one.

This concept has been extended to the digital data with some algorithms that produce a digital watermark. The general idea is to modify each pixel of an image with a specific method to hide some extra information. If you know how you marked your image, then it is easy to apply the reverse algorithm to extract the pixels which had been modified. According to the way you modified the pixels, you can then recover the message hidden. At the end of the process the eye cannot see the difference between the original image and the watermarked image. This idea works because the eye cannot see the difference between two very closed pixel values : in general images values are between 0 and 255, however the eye can distinguish only 80 values different. That means that between a pixel who has the value 240 and his neighbor who has only 239, the eye will not distinguish them. So if you change the value of each pixel then a human being will not see any difference.

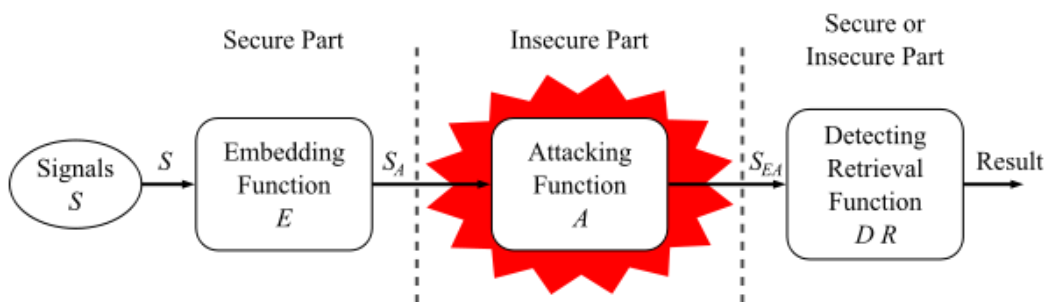
NB: even if the comparison with the banknote helps to understand the general way of use, the concept is quite different : you modify the image in order to code a message which is only a stack of 0 or 1, you do not hide another image by superimposition. But by hiding a message you can still prove the authenticity of the image, that means that you can protect your data from copy.

The researcher in charge of the micro CT-scan at Wits is Dr. Kris Carlson. He and his colleague Lee Berger decided to do something to protect the images that have been produced by their machine. So that is one of the reason I came to South Africa : to elaborate a little software that could watermark all their images. This software would only be the first step in the watermarking process of Wits if they are convinced of the use of such methods.

## B) Needs analysis

Since there were no already existing software before for this university, and I had a few knowledge about this issue, I started by reading articles and web-pages about digital watermarking. It helps me to understand globally the functioning of different algorithms and it reminds me some lessons I had at school.

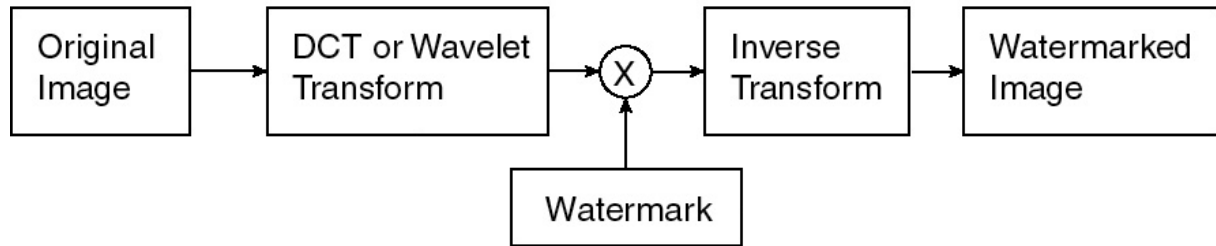
The first thing to know about digital watermarking is that the goal of each method is to be the most robust to attacks. There are two types of attacks : the passive attacks and the active ones. Passive attacks means that you damage the code by processing the image. For example, if you increase the global brightness or the contrast of the image, you will modify all the pixels. This modification will distort and degrade the message that you have hidden. In the best cases you can still recover some part of the message, but in worse cases you will not find something readable. Rotating, compressing or cropping the image are other types of passive attacks. Active attacks is when a person wants to break intentionally the message hidden in order to remove it or replace it by his own message.



*General digital watermark life-cycle phases.*

I also learnt that all the algorithms are first divided in two parts : the ones which are called "blind algorithm" and the "non-blind". The difference is easy to understand : for the "blind algorithm" family you only need the image with an hypothetic mark on it to recover the message, as opposed as the other family for which you need both the original image and the image you want to extract the message.

A last point is the "space" where the algorithms work. For some methods you embed the message directly in the pixels, without doing any computations before, for other you first compute a Fourier Transform (FT) or a Discrete Cosines Transform (DCT) on the image and only after this step you hide the message and you finally do the reverse transform. Each method have pros and cons : some are faster, others are more robust to one or several specific attacks. Unfortunately there is no algorithm that resists to every kind of attacks, that means that I had to chose one method that matches best with the needs of Wits university.



*Figure of the general functioning of algorithms.*

After this first step of global understanding I had a first meeting with Kris Carlson to define the most important points for him. Globally after this meeting I had some key point that my software should respect :

- the algorithm has to be blind : we do not want to compare the original image with the marked one to recover an hypothetic mark.
- the algorithm has to resist as much as possible to JPEG compression.
- the algorithm has to resist to cropping. That means that even if you remove some parts of the image, you can still find the mark.
- the software will process only TIFF images to begin. The reason of this choice is that TIFF is a very common extension for this kind of images and every software reads this extension.
- the message hidden should be between 10 and 30 characters, in order to put the copyright.
- the software should work only on gray images, but should not bug if the user gives color images.
- the software should be easy to run and have a little graphic interface.

After having talked to Gerard Subsol, he gave me an existing algorithm coded by his institute and that watermarks some images. I then modified these lines in order to get something that could respond all the issues given by Dr. Carlson, however it helped me a lot to get something that initially works.

## 2. Segmentation tools

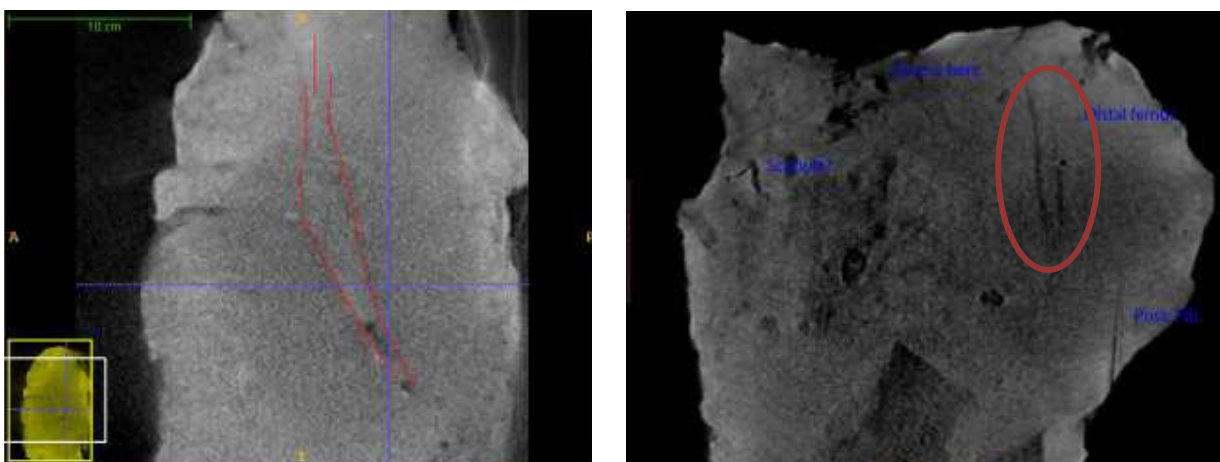
The second part of my work was also to talk with people from the department of paleosciences in order to see what are their needs and how computers could make their life easier to do their research. The goal of this work was not really to make a software or define a new algorithm that could revolutionize all the paleosciences field but rather to explore, perform some research on the internet about existing methods and eventually show some experiments to the paleontologists.

### A) Computer-aided identification of fossils in blocks

I already introduced this problem in the introduction but let's remind some little points : in South Africa most of fossils are found in big blocks of rock. The bones are very fragile and it is extremely difficult to extract the bone in the block without damaging it. Paleoscientists had recently the idea to scan it with a CT-scan to extract the fossil digitally.

When you find bones in a piece of rock, it is highly probable that in other pieces of rock that are next to first one contain bones, even if there are not visible. Researchers have lots of blocks of rock and they do not have studied all of them, because it is quite long to scan all the rocks and even longer to stay behind a screen and process all the images slice by slice.

This is why it could be really useful to segment automatically the bones in the blocks of rock : we could ask some preparers or technical people to scan the rocks, and then the computer could run an algorithm that detects automatically, even roughly, hypothetical bones. After this process the researcher in paleontology could segment more accurately the bones if they think that is worth studying it. The key point in this method is that the computer does not have to be very accurate, but just to detect global shape : if it makes mistake because it is not human bones but monkeys or others mammals it is not a big problem because it would take only a few minutes to the scientist who works in this field for many years to confirm or exclude the hypothesis made by the computer. And it will still save a lot of time to researchers because they do not have to process every parts of all the blocks found but only the parts indicated by the computer.



*Scan images showing the presence of a long bone (femur) in a block. The bad quality of the image due to the density of the rock is a big problem for image processing.*



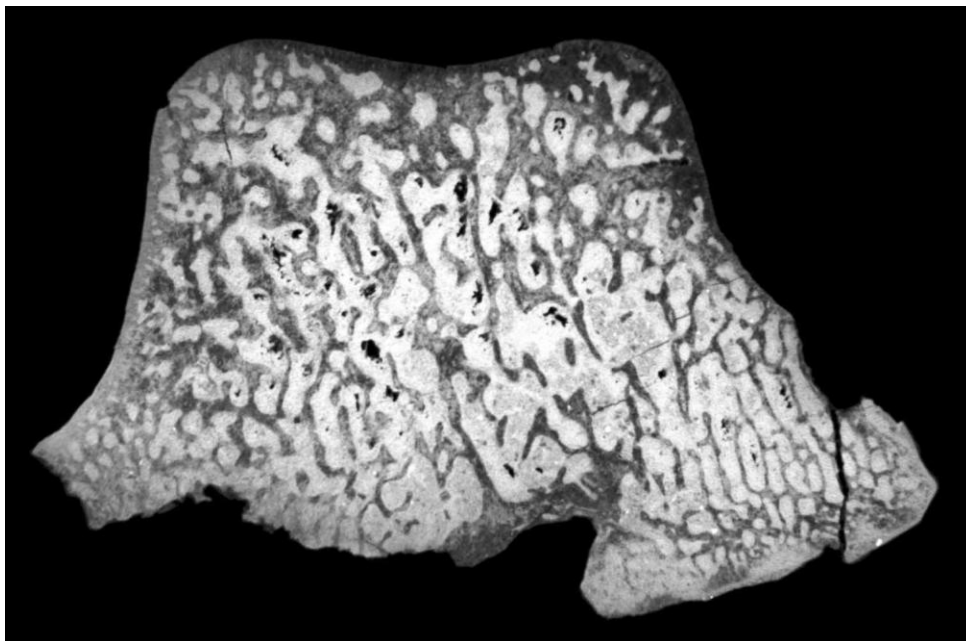
As we can see on the previous images, one of the biggest problem of segmenting automatically the bones is the quality of the image. The images are very noisy and the details are not very visible.

The first step of an algorithm that could alone and automatically find the bones would be just to point out all the shapes that he has found. The second step would be to identify what is the shape he has found, or in other words the name of the bone he thinks he has found.

I talked with Kris Carlson and his colleagues Tea Jashashvili and Dominic Stratford about this issue and they were all convinced that it would be very useful for them to have such a tool to process faster the selection of the block to study. They also pointed out that it would be also useful for the mechanical process of the bones : after having determined where are the bones, you can remove entire part of the rock and being sure that there is no bone inside.

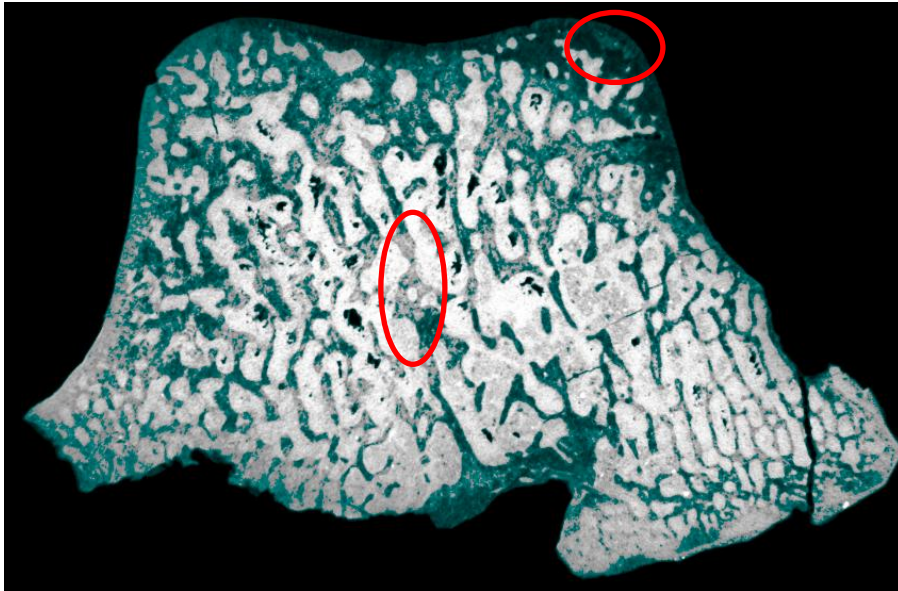
## **B) Automatic segmentation of the trabecular bone**

I also talked with Kris Carlson about another problem that they commonly encounter when they study bones : the extraction of the trabecular bone in a fossil. An example of these kinds of bones are showed below.



*Trabecular bone (also called spongy bone). The darker part is the trabecular bone and the lighter part is the matrix (kind of rock)*

The study of these bones is very important in anthropology : researchers study the global shape, orientation and size of these bones. The computer could help a lot to do some statistics about it but the problem is that it is very long to segment manually these bones. The idea here would be to extract automatically from this image two general regions : the trabecular part and the matrix. It is quite difficult to segment very accurately the bone because some part of the images do not have the same intensity even if they are belonging to the same part.



The two circled regions show the difficulty to extract the bone only by a criteria on intensity. If we select all the pixels that have the same values we cannot extract properly the trabecular bone. The grayscale values is not homogeneous which increases the difficulty to segment very accurately the bone. On the top right we have a region that does not belong to the trabecular bone whereas in the middle some parts are not selected and it should be.

This is why anthropologists are segmenting manually the bone. With an algorithm that could do the work for them they would save a lot of time and could focus more about the results in where they are interested : the shape, the orientation, the size and other data important to do comparisons between species and bones.

### III. Work and Results

#### 1. Watermarking software

##### A) The algorithm

Since I had an algorithm from the ICAR department that watermarks an image I had a good starting point. The general functioning of the algorithm was the following :

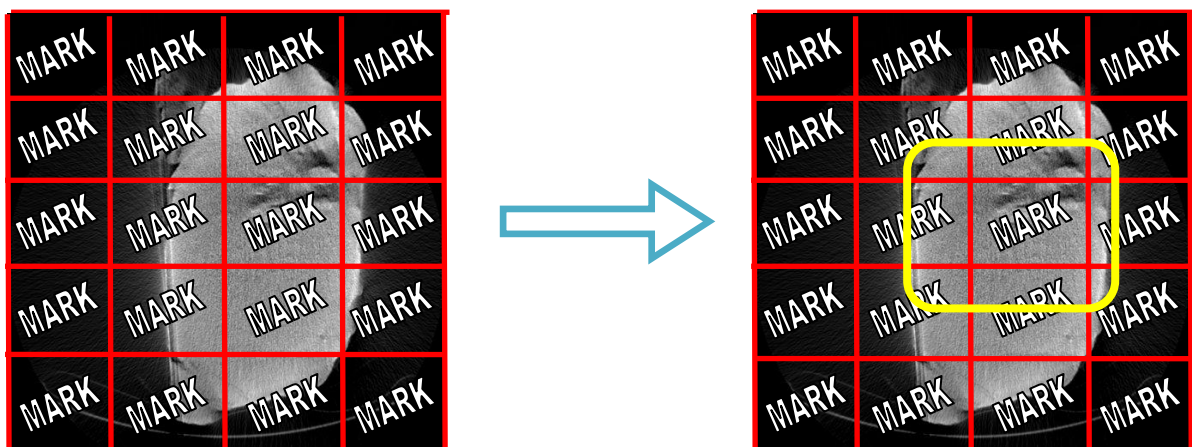
- open a file (extension .PGM)
- computes the Discrete Cosines Transform (DCT) of the image
- insert a message with the Cox method in the DCT values
- computes the reverse DCT
- save the image

The Cox method is a blind algorithm very used in the watermarking field. It is more detailed in the article : **Secure Spread Spectrum Watermarking for Multimedia**, (Cox - Kilian - Leighton and Shamoon).

This algorithm provided by LIRMM could not be used directly for many reasons. The first reason is that I could not read TIFF images with this method. The second problem is that this method is not robust to cropping: if we cut the image the message is lost.

To solve the first problem I had to use an external library that reads TIFF images : libtiff. Since the TIFF file is a quite complete and portable extension it has many options and it took me lot of time to understand all of them in order to open every TIFF file types.

To solve the second problem I decided to divide the image in sub-images and then to mark each sub-image. Thanks to this amelioration if we select an area that is twice bigger than the sub-image we can be sure that we will find the mark.



*If we subdivide the image and insert a mark in every sub-image then we can recover it easily even if the image is cropped.*

We could implement this idea because we had defined with Kris Carlson before that the size of the message should be between 10 and 30 characters. The length of the mark that we can embed in an image depends indeed of the size of the image. That is why I decided to put as an option the size of the sub-image we want to process.

To extract the message the algorithm given by the ICAR team was the following :

- open a file (extension .PGM)
- computes the DCT of the image
- extract a message with the Cox method in the DCT values

I modified the algorithm above a little bit. In fact, since the message is embedded in every sub-image, I did not compute the DCT of the whole image but of an area that is the size of the sub-image. Then I extracted a message with the Cox method. The problem is that we have no idea if the message extracted is correct, and if we have to compute the DCT of another area (just shift the area to the right for example). That is why in every message embedded I add 4 prefix letters, for example MARK. In this case every message inserted looks like MARKthemessageIwanttohide. Thanks to these letters we know that if the message extracted does not start by MARK it means that the message is not well synchronized and we have to try on another area.



*If every message starts by the letters MARK, it is easy to figure out if the area selected is correctly synchronized.*

## B) The conception

Since I decided to implement a graphical user interface (GUI) I implemented a solution based on the pattern Model View Controller (MVC) even if it was a very little project :

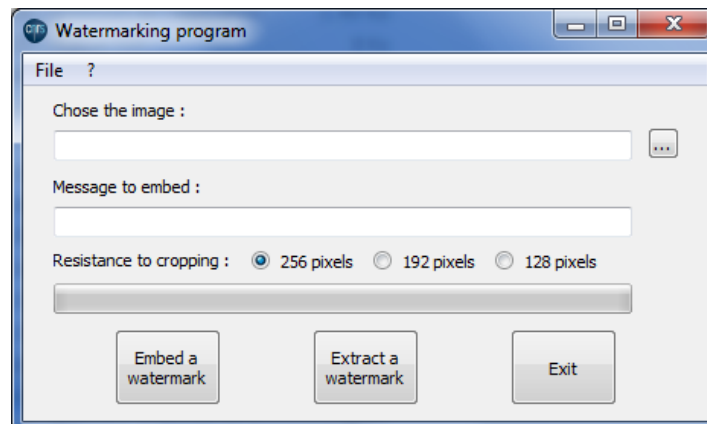


*The data files.h represent the class I needed to implement my software.*

To sum this figure briefly, this is how it works : the View receives all the information and give them to the Controller, if the action is valid then the controller gives the instruction corresponding to the Model which computes what it should compute. Whatever the result is (positive or negative) it gives it to the Controller which then gives to the View the information it should display to the user.

### C) Results

I implemented a software that run under Windows. I used the library Qt to do the GUI :



*Interface of the software.*

It can watermark all the tiff images which are grayscale valued. I ran it on sample data in order to test it :

Name	Size	Pixel type
Cellule.tif	512x512	8 bits
Foetus.tif	1660x1264	16 bits - unsigned
Artificiel.tif	512x512	16 bits - signed
LargeHead.tif	1716x1716	16 bits - unsigned
LargeHeadSmall.tif	738x858	16 bits - unsigned

It worked on every image and the extraction was quite quick (less than 5 seconds). It also worked if the image is cropped even if it can take a long time to extract the mark if the image is very badly synchronized. I also tried to compress the image with the JPEG algorithm and I got this result :

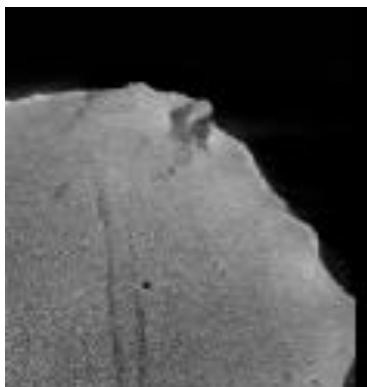
JPEG compression factor	Message 1 (length 128 bits)	Message 2 (length 64 bits)
<b>QF = 100</b>	100%	100%
<b>QF = 90</b>	94%	98%
<b>QF = 80</b>	20%	30%
<b>QF = 70</b>	4%	1%

The percentage given represents the similarity with the message introduced. We can see that if the compression is too high (= low QF) then the mark is completely lost. However we still recover the mark with QF=100 and QF=90 which is one of the requirement defined by Kris Carlson.

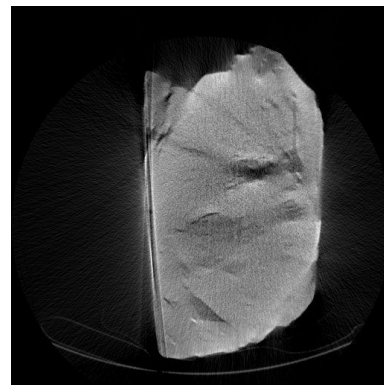
## 2. Segmentation tools

### A) Computer-aided identification of fossils in blocks

I did not implement any program for the problem of segmenting automatically bones in blocks. The major problem that I encountered is the noise of the image : it is impossible to process the images if even by segmenting manually you get difficulties it is quite impossible to do it automatically. I tried to apply several filters but it did not improve that much the result. With my tutor we had the idea to use super-resolution algorithms by combining the images scanned in different orientations but we could not do it because the block was too big to scan on different orientation. At the end I spent several days on this issue and since I could not have good results and I did not have enough time to work more on it.



*Very low contrast. We can barely see the bone.*

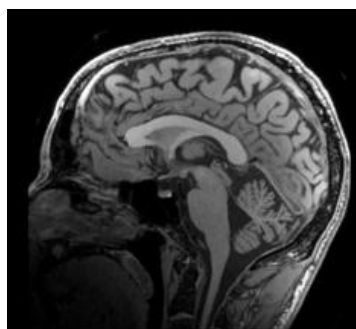


*A lot of beam-hardening artifact.*

### B) Automatic segmentation of the trabecular bone

To work on the automatic segmentation of the trabecular bone I decided to work with library CImg. It is an open-source library that allows very basic image processing.

To solve the problem of non-homogeneous grayscale values I used an algorithm much known in the MRI which is called the bias correction algorithm. Since images are better than long sentences this is the effect of such algorithm.



*MRI images.*

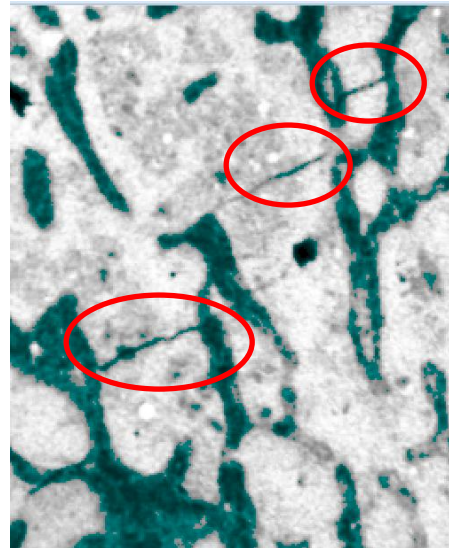
**Left:** original image. **Right:** After the bias correction.

This kind algorithm computes a general bias on the image and correct the values of it:



**Left:** original image. **Middle:** bias computed.  
**Right:** corrected image.

This improves a little bit the quality of the image but there is still problem to do a segmentation based on threshold. There are indeed some zones on the image that are very dark because of crackling and times damaging. Those zones should not be considered as the rock but as the trabecular bone.



*Crackling. The threshold includes this as part of the rock.*

I looked in the literature to figure out if there were some other approaches to use. I found that I could use methods based on level set. However I did not have time enough to explore more this solution.

## IV. Personal feelings

### 1. Project difficulties

I encountered some difficulties during my internship but I managed to overcome them with time and help of my tutor.

The first difficulty was obviously the language. If it is not very difficult to speak English with someone about informal questions, it becomes much more difficult when you are talking about technical questions. The reason why it was so difficult is that when I wanted to explain something I often knew the French word to express it but not always the English equivalent. I also had problems with the accent and following conversations at the beginning but it has been fixed up after a few weeks. I got also difficulties to understand paleo-scientists because they have very specific vocabulary and expressions.

The fact that my computer sciences tutor stayed in France was a bit difficult at the beginning : since I did not have much knowledge about watermarking it was hard for him to explain him all the concepts and algorithms. Luckily with internet and telephone we could communicate easily. Everything went better after some days and I could finish in time the work I had to do.

### 2. Adaptation

To come in a new country with a new culture to discover is not an easy task moreover if the country is 10 000 km far from France. I was not scared to come in South Africa but with what everybody told me about the security and the problems that this country has I was a bit worried about it. Everything went perfectly well and I must say that I did not feel the impression of insecurity. I settled down in a student residence and I got used to this way of living.

To get along the institute of Wits was very easy : everybody was friendly and there were lots of foreigners which eases the integration. All in all every little apprehension has vanished quite quickly.



## V. Conclusion

This internship was a great experience for me in several ways. Even if it was not my first experience of working in a research laboratory, it was very interesting and challenging to work in an international context and to work by myself. This experience in this institute taught me how the research world is functioning and that it is very important to take time to read what exists before making any decision.

This experience abroad also helped me a lot to be more confident with my English skills. I appreciated a lot talking to foreigners and sharing their point of views about the way they work and they study.

Finally the multi-disciplinary work is something very stimulating and this internship confirmed me that I wanted to work in the field of medical imaging and more generally bio-informatics.