

A software for quantitative analysis for intervertebral movement based on medical images

Júlia Fernanda Moreno Pinheiro

Instituto Superior Técnico, Lisboa, Portugal

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Abstract

Spine related problems have a huge impact on modern societies being some of the most prevalent and limiting ones. A correct diagnostic, in early stages, is extremely important in order to start the correct treatments for each case and prevent further damage. The creation of a software capable of quickly analysing the spine condition or its evolution during treatment or a post-surgical period was the goal, so that a more precise and efficient procedure is given to each patient. To have a good set of parameters enabling a correct evaluation from end-range radiographs the parameters calculated were the Center of Rotation (qualitative analysis), the Range of Motion (quantitative analysis) and the measurements of the vertebrae and disc of that segment. The tool has its sensitivity tested and the result revealed a higher instability in the disc height measurement while having a reasonable average error associated with the method, making it a robust and solid tool capable of integrating the clinical practice.

Keywords: Biomedical Engineering, Spine, Vertebrae, Center of Rotation, Quantitative Analysis, Range of Motion, Biomechanics

1. Introduction

Spine kinematics are often assessed through radiographs obtained, for example, with an end-range movement (flexion-extension). This type of analysis is important for disease diagnostic and monitoring of its evolution, as well as to analyse the performance of spinal devices and treatments in the movement restitution provided. As a computer aided diagnostic software it can provide quick results using standard exams (x-ray images) as input, without the need of expensive and prolonged ones. Specifically it can be used to compare how different artificial discs act on the patient after a total disc arthroplasty [5].

A semi automatic process to obtain kinematic parameters, such as the Center of Rotation (COR) or the Range of Motion (ROM) of a segment, will re-

duce the time needed to complete an analysis and therefore having a convenient tool for clinical use [6]. The measurement of the COR value is specially important for analysing the condition of the spine since its values are very well limited and defined for the normal and pathological conditions [8]. It is calculated fixing the inferior vertebra of the segment and analysing the rotation of the superior vertebra in that condition (Figure 1). This allows the calculus for the location of the COR and its comparison to the normal regions for the segment in study indicating directly if the movement is being done correctly or not.

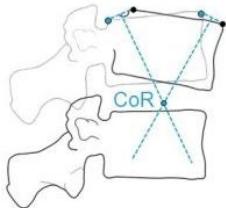


Figure 1: Representation of the COR calculus and location.

It allows for a quantitative measurement of the movement, providing information on how the spine is moving, in the correct way or not, instead of showing only how much it moves regardless of the action, per se, as it is in the case of a ROM analysis.

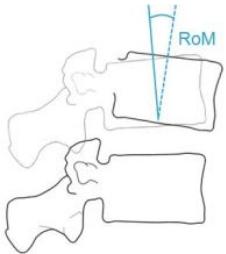


Figure 2: Representation of the ROM calculus and location.

ROM is calculated in the same conditions as the COR analysis, i.e., fixing the inferior vertebra of the segment and analysing the rotation of the superior one, Figure 2. In this case what is evaluated is the angle between the flexion and the extension. The angles for each segment are small since the movement of the spine is a complex system involving all segments and therefore the whole movement may have a big range but the constitutive segments have small ones, which combined result in the whole range of the spine.

An incorrect movement of a spinal functional unit (two vertebrae with the intervertebral disc in between) can explain low back pain or even degeneration of adjacent segments. Several specialists might benefit from such a software, not only doctors but physiotherapists, researchers and even companies that need a warranty that their product is reliable and produces the expected result.

1.1. Methodology

The objective of this work is thus to develop a computational tool capable of calculating these parameters, in a semi automatic way, based on the patient medical images. The software was built in MatLab. The result is a Graphical User Interface (GUI) easy to use independently of the user background and capable of comparing healthy with pathological, or post-surgical, parameters.

1.2. State of the Art

Nowadays no tool is used in the clinical practice with the intent of having a direct evaluation tool for the spine motion, although it would make possible for quicker diagnosis and better monitoring of diseases and interventions.

Despite this, some software already exists that could be used for that end although it has not been done. The majority analyses posture problems, determining if the spinal curvatures are maintained or have any kind of pathology, added to a quantification of movement through the Range of Motion. However, this type of analysis does not provide information on whether the movement is correct or not. For that, another parameter revealed useful, the Center of Rotation. The inclusion of this value enhances the analysis, granting more reliable results of the spine condition.

Once again, some teams have already done some work developing very complete software [7, 5, 1, 6]. Abbasi *et al* [1] developed a tool based on the most accurate way possible to perform a COR analysis [3] but faced the same problems as in the presented work. An automatic segmentation is a difficult task to perform with x-rays since the contrast on the image is poor and the image in itself is usually very noisy. The result is a software that does a semi-automatic analysis based on points selected by the user. Spineview [13] is probably the more complete software of this kind, integrating several important results that are useful in a detailed analysis.

2. Computational Work

As previously mentioned the platform to build this work was a GUI, in MatLab, chosen in order to

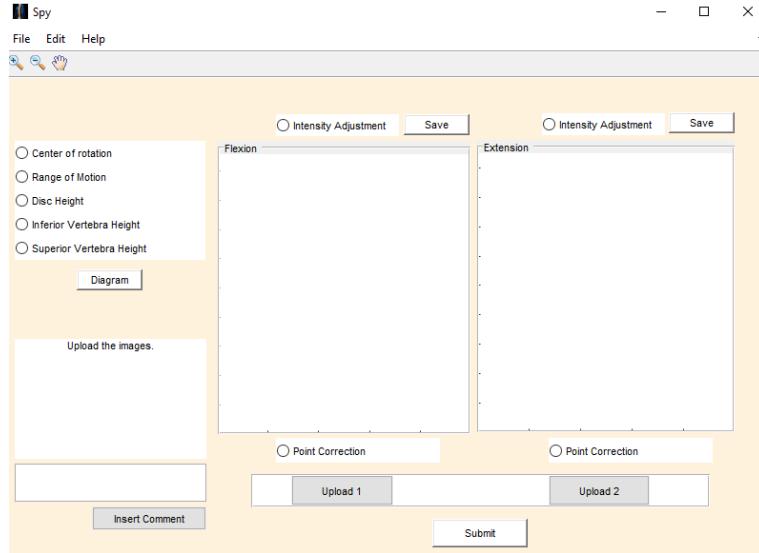


Figure 3: Graphical User Interface which enables an easy adaptation to the user and a fast analysis of any spine in study.

make a user friendly environment that allows a simple usage to all possible users.

The design was thought in order to have all the possibilities available to the user at sight, without the need of several windows or to open functions in hidden menus. The possibilities for each step are shown through the whole process and are simple to use.

Following that line, all the steps for a successful analysis were created in an intuitive way for the user and with little information on the main points so that nothing may be forgotten.

The text console (in Figure 3, the "Upload the images" element) serves for that purpose, giving brief instructions during the whole process, either for guidance through the steps as to inform the user when something is done wrong or in the wrong order.

The analysis is done using two x-ray images, one in full extension and the other in full flexion. These will be the anchors to all the analysis and it is through them that the segment in study will be evaluated. As the medical images being used are known for its low contrast, an intensity adjustment filter was added to the window in order to allow the user an extra adjustment that may help to the distinction between structures (Figure 4).

It is also important to refer that below the Menu bar there are some tools for image handling that allow zooming in, zooming out and panning the image in order to see the regions of interest more clearly.



Figure 4: The use of the button for Intensity Adjustment allows a better contrast in the image making it easier to identify the structures.

To complete an analysis the following steps are to be done: 1) give a name to the study being done; 2) upload the radiographs, one of a full flexion and another of a full extension; 3) Click the Submit button; 4) select the limits of the vertebrae in the segment in study with a point for each vertice, i.e., four points per vertebra, eight points per image, sixteen points in total; 5) confirm that the points selected are correct and that the calculations may begin; 6) finally the contours of the vertebrae will appear rep-

resented in the images which means that the results have been completed.

The results can be seen in the Text Console, according to the buttons selected above. When the analysis is complete a report file is automatically created with the results. Comments from the user may be included using for that end the comment editable bar and button below the Text Console.

There is also a possibility of seeing the results in a diagram format, more simple without the images below the contours. To see the results using this option it is only necessary to click the Diagram button.

In any point of the analysis the user can save an image of what is being seen in the axes, exactly as it is at that moment. To do so, the Save button, on top of the axes should be clicked and a window will appear asking for the name in which the image should be saved.

If in any point the selection seems misplaced, either as a whole or in the case of a single point there are several options to correct that situation. Below the axes there is a Point Correction button that when selected opens a new window asking for the position of the point to be corrected, according to the order in which the points need to be selected (Figure 5).

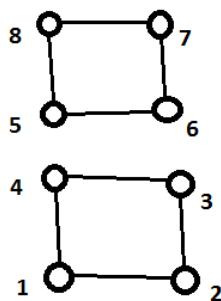


Figure 5: In order to have a correct analysis the points selected by the user must follow this specific order.

In the end of the selection of the sixteen points there is always a question whether the analysis may begin or if the points need to be redone. For more

extreme cases it is possible to redo the whole analysis, using the Reset Menu option, where both the markings and the images are erased and the user shall begin the selection again.

Some other functions were implemented such as the option to Save an Analysis and Open it later, having the results displayed in the GUI as if the analysis was done at that moment.

3. Discussion

The implementation of the algorithm to compute the values intended was done following the basic definitions of the parameters that are obtained with simple geometry analysis. The basis for those computations are the points the user selects and therefore the results come with influence of the accuracy on the location of the points.

To have valid results capable of being trusted and therefore used as a relevant parameter for evaluating spine motion there was the need to prove that the software works correctly.

To do so three types of tests were made, the first consisted in the use of artificial data, in this case points, to be given directly to the software without user input, and having therefore confirmation on the correct output from the algorithm; one comparing computational results with manual results, just like these parameters are calculated nowadays, using the radiographs and superimposing acetate paper for the point selection which will be the base for the calculations; and a comparison between the results given by the present work and SpineView [13].

The artificial tests were done with limit cases, not necessarily representative of a real situation, but that would allow the complete control over the desired parameters. Knowing precisely the absolute value of the output the comparison was direct to make. The points were created in order to have vertebrae represented as squares, with three units of side. Four tests were performed, with the superior vertebra rotating around the sixth point (as seen in Figure 6) the amount of 0° (equal images in flexion and extension), 90° and 180°. The fourth test was a symmetry test where the flexion repre-

Table 1: Results from manual and computational analysis for the pre-surgery data. It is possible to see the similarities between the two and the major difference in the time spent performing an analysis.

	CORx	CORy	ROM	Vertebral Height Proportion	Time Spent (min)
Manual	-0.55	-0.2	12°	1.1667	30
Computational	-0.67	-0.29	17,16°	1.0643	3
Absolute Error	0.12	0.09	5°	0.1024	27
Relative Error	21.82%	45%	41.67%	8.78%	90%

Table 2: Results from manual and computational analysis for the post-surgery data. It is possible to see the similarities between the two and the major difference in the time spent performing an analysis.

	CORx	CORy	ROM	Vertebral Height Proportion	Time Spent (min)
Manual	-0.8	-0.6	7°	1.1029	30
Computational	-0.78	-0.73	7.81°	0.9773	3
Absolute Error	0.02	0.13	0.81°	0.1256	27
Relative Error	2.5%	21.67%	11.57%	11.39%	90%

sentation was the symmetric of the extension. Representation of all the tests are shown in Figure 6. The results from the artificial tests only confirmed the correct values from the software and therefore validating the accuracy of the method isolated.

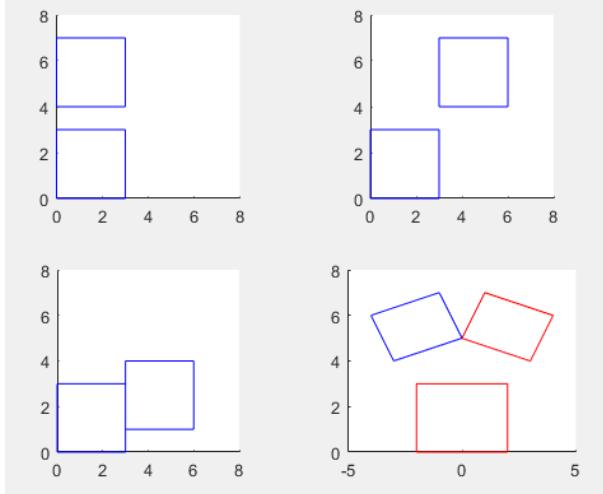


Figure 6: Representation on the artificial tests performed. The upper left was the flexion for all simulations of 0°, 90° and 180°. The last image represents both flexion and extension in the symmetry test.

In the Manual testing the idea was to compare what is done nowadays for a normal analysis of this type and its computational equivalent. The resem-

blance between the result in the computational form or in the manual form is evident, as it is possible to see in Figure 7. The results were also similar and even though the relative error, when comparing both results, may be considered somehow high, in Tables 1 and 2, it is important to see that taking into account the dimensions of the spinal structures considered and the scale of the coordinates these kind of errors in the latter are not as relevant to the whole.

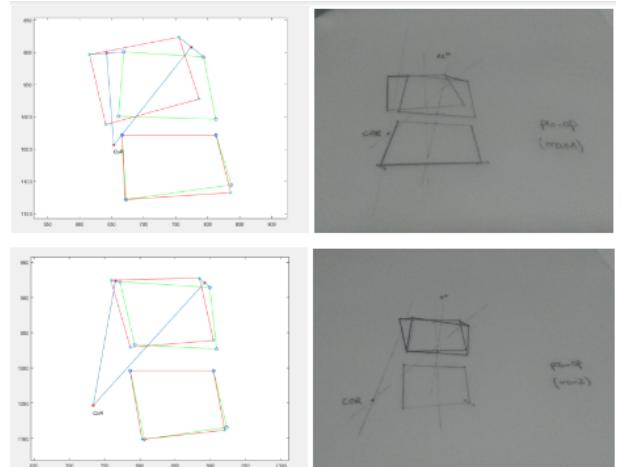


Figure 7: Visual representation of the COR results both in computational and in manual analysis.

At last, the comparison between the results given by this software and by SpineView were analyzed,

having the same images as basis.

The cases in study were of three different situations, all of the same patient but one from a pre-surgery condition, one from a post-surgery condition temporarily close to the intervention (two months) and another from five months after the surgery. The naming for this simulations, for simplicity is done through the enumeration of the cases, being SpineView1 the test performed by SpineView for the pre-surgery images, Sim1 the analysis performed by this present work for the same condition, SpineView2 for SpineView analysis of the initial pos-surgery study, Sim2 for this work and SpineView3 for the SpineView analysis of the five month follow up, with Sim3 for the same analysis but with this software.

The results had some relevant relative error (Table 3) although it is important to note some things: the error given by SpineView referring to this calculations has an average of 74% for COR location in x and of 117% in y, which is a very high number for uncertainty. Therefore the comparison is not very relevant to make since from the beginning it is known that the values of SpineView come with a big uncertainty associated.

Table 3: Comparison between the results given by this Software and SpineView, when performing the same analysis.

	CORx	CORY	ROM
SpineView1	30	-46	8°
Sim1	47	-20	5.36°
Relative error	57%	57%	33%
SpineView2	-7	9	6°
Sim2	25	20	2.96°
Relative error	457%	122%	51%
SpineView3	33	94	11°
Sim3	38	86	10.50°
Relative error	15%	9%	5%

In order to assess the robustness and accuracy of the software here developed, some sensitivity tests were performed. These consisted of choosing a "rea-

sonable" range of error for the variation of the coordinates of the input points, computing the outputs (coordinates of the CoR, angle of RoM, vertebral heights and disc height) and then the error associated with each one for all combinations of variations in the x-axis and the y-axis.

The original points used were assigned in a real user-run test of the software, and are displayed in Figure 8 along with circles representing the chosen range of variation for each point. That range was chosen as -15 from 15 pixels, with steps of 0.1 (in image coordinate units), as a rather conservative range, since a real user, during a real analysis, would not perform such drastic errors.

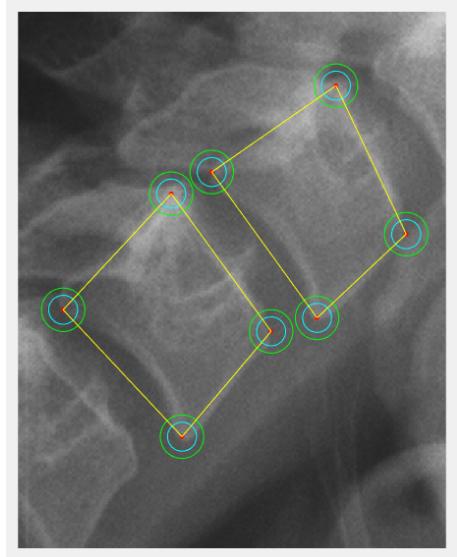


Figure 8: Graphical representation of the limits of 15 and 10 marked as the conservative and less conservative range for user markings.

A less conservative approach would be from -10 to 10 pixels (image coordinate units), which is also represented in Figure 8. A sensitivity test was done to each point separately, underlining its influence in the general outcome and the results are shown in Tables 4 and 5. In those it is possible to see the average percentage of error associated with the change in location of all the points selected by the user, one at a time. It is possible to see the maximum error and the average for each parameter. The parameters represented are those calculated by the

Table 4: Average percentage of error associated with all the points selected. (-15:0.1:15)

	COR		ROM	V1h	V2h	Dh
	X	Y				
Max	24.70	36.30	44.30	8.30	9.35	154.09
Mean	2.76	4.76	15.07	3.15	3.37	43.47

Table 5: Average percentage of error associated with all the points selected. (-10:0.1:10)

	COR		ROM	V1h	V2h	Dh
	X	Y				
Max	7.74	12.33	29.23	5.45	6.15	102.57
Mean	1.65	2.89	10.05	2.10	2.25	28.18

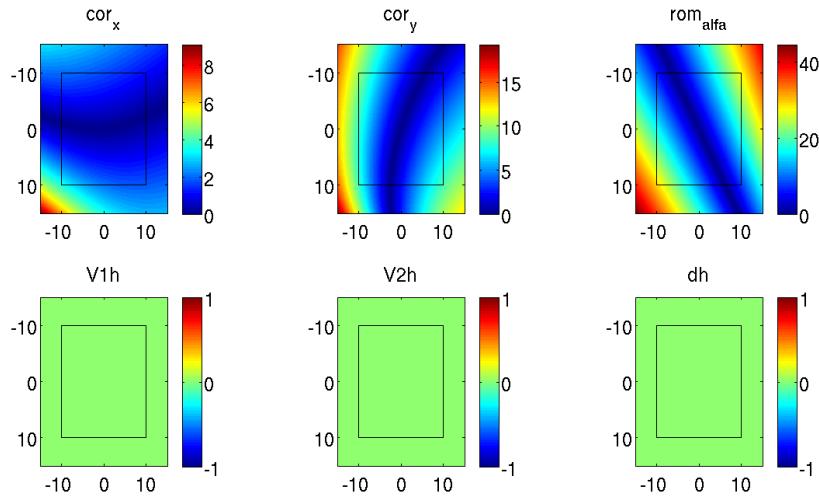


Figure 9: Relative error of point 4 in flexion.

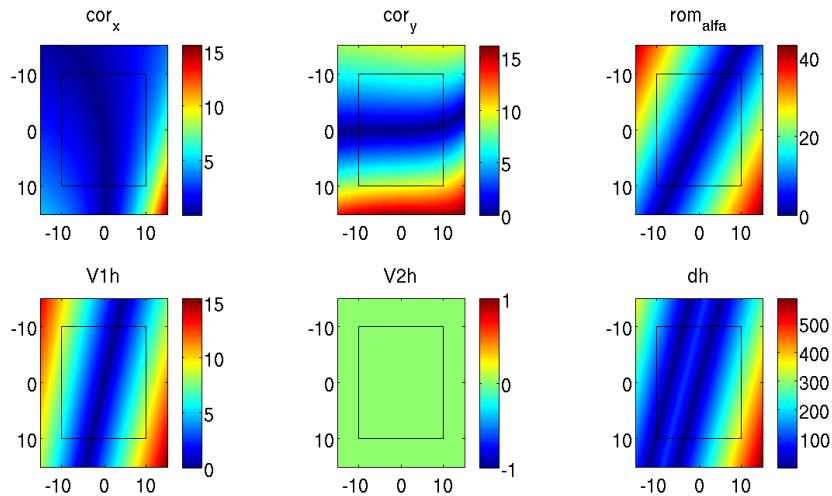


Figure 10: Relative error of point 4 in extension.

software, namely, CORx and CORy for the location in x and y of the COR, respectively, the ROM, the height of the inferior vertebra of the segment (V1h) and of the superior one (V2h) as well as the disc height (Dh).

In Figures 9 and 10 it is possible to see represented the percentage of error in a more visual way. It is represented the limits for -15 until 15, with the representation of the limits for -10 to 10 as the rectangle in black. Each graph represents one parameter of the ones calculated and two examples are shown, for changes in point four of the flexion image, and on point four of the extension image.

4. Conclusions

The use of software in medical aid for diagnosing or monitoring of evolution of a given disease or condition is of extreme importance, since it gives an almost immediate result that is directly applicable in clinical use.

After looking at the validation tests and the sensitivity analysis some conclusions can be drawn. These type of analysis highly depend on the user and the capability of delimiting the vertebral structures. These parameters, and more importantly for the COR, since it can be considered the main result of this software, are sensitive values that may have relevant differences with a small discrepancy in the points selected. Even knowing this from the literature [4, 9, 12, 10, 11, 2], analysing the sensitivity of the method we see that the average error associated with this parameter for user-like simulations is not that high, as can be seen in Tables 4 and 5. The disc height is the more unstable parameter and this is understandable since all the points selected are included in the calculation of that parameter and therefore a small deviation in any of them leads to an error that accumulates with the deviations in the other points, thus leading to a highly unstable measurement.

The big difficulty in analysing and comparing different types of analysis or even different software is that the information is dealt with in different ways. There is no standard methodology, so far, for this type of evaluation. The limits for the basis of the

analysis were studied by Amevo *et al* [3] but for the computational steps and representation of the results there is still a big discrepancy between the research groups working on it [1, 6, 8].

One of the problems identified in other softwares was the impossibility of changing the user input during the analysis, since sometimes while analysing the results the user finds a misplaced point, or one that is not coherent with the remaining locations. Solving this problem, in this work, for accuracy, it is possible to correct a point without the need to perform a whole new analysis.

The major advantage of this tool when compared to others is the adaptability that it allows to any desired end. Along with the possibility of being in itself adaptable to the user, it can adapt to the situation. It is possible to be set as a MatLab package in order to be used and improved by researchers and other developers, in a more technical branch, but also for direct use, like for doctors in clinical practice, or therapists, as a simple, single executable file without any development intent, only simple usage.

5. Future Work

Creating a software from the beginning is a complex process that involves several layers of development. The main work was done and the main objectives were achieved: the algorithm was tested and the GUI is simple and functional. Despite this, there is always more to be done, specially if the final intent is to have a tool powerful enough to be used in the clinical practice, something which this work is very close to achieving.

The main changes would be regarding the way of selecting the vertebrae contours, either by having more points for each vertebra or by finding a way of having an automatic tool that is capable of distinguishing the structures in the x-ray images, in order to minimize both the user and the method error.

It is also important to extend the method to a spinal region (cervical, thoracic, lumbar, sacral), for example studying the condition of the cervical portion, or even to the spine as a whole, instead of

having it only for a segment, allowing for a better understanding of the behaviour of the complete spine as result of a localized or generalized pathology.

There are also some advancements possible related to the GUI design, like making it more adaptable to the user, and having different focus in the visualization of results or in the type of features the GUI can have, depending on the type of information intended.

On a general note there are some important steps to be done in order to make this technique more reliable and reproducible. First it is essential to create standard routines for this analysis, not only by following the work of Amevo [3] but also by creating a common way of presenting the results.

More focused on the clinical application and in its relevance for the people, more studies need to be made in order to correlate the locations of COR through the spine with pathology, analysis patterns and making it possible to have a quick diagnosis based on the type of results from that patient exams. Having this kind of information well established and statistically relevant, it would be possible, in an automated way, to make fast and accurate diagnosis on any routine consultation which would determine a detection in early stages of the pathologies and therefore allowing the beginning of correct and specific treatment, as well as preventing further problems.

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