Postural Assessment in Dentistry Based on Multiple Markers Tracking

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Abstract

Postural assessment is a fundamental aspect to prevent long-term Musculoskeletal disorders (MSDs) due to fatiguing jobs. Operative dentistry also belongs to this category and we developed a Computer Vision approach to automatically analyze the dentist posture during operations obtaining an evaluation of MSD risk according to some well-established criteria like RULA and NERPA. In particular we analyze three different set-ups where the dentist operates with naked eyes, medical loupes or using a surgical microscope and we compared the postural effects of these three different configurations. The results present a significant improvement in posture using the microscope and validated our approach as a feasible and effective method to assess posture in fatiguing jobs. The proposed approach allows a continuous monitoring of job activity evaluating accurately posture criticalities. Furthermore the risk of MSD based on international criteria is evaluated in an objective and accurate way. The whole proposed system follows a non-invasive approach based on Augmented Reality markers tracked from a distant camera and can be applied to effective monitoring different working activities providing an accurate and objective estimation of MSD according to modern posture assessment criteria.

1. Introduction

Musculoskeletal disorders (MSDs) affect the muscles, nerves, blood vessels, ligaments and tendons. Workers in many different industries and occupations can be exposed to risk factors at work, such as lifting heavy items, bending, reaching overhead, pushing and pulling heavy loads, working in awkward body postures and performing the same or similar tasks repetitively. Exposure to these known risk factors for MSDs increases a worker's risk of injury.

Work-related MSDs can be prevented, in particular Ergonomics (i.e. fitting a job to a person) helps lessen muscle fatigue, increases productivity and reduces the number and severity of work-related MSDs. Work related MSDs are among the most frequently reported causes of lost or restricted work time. According to the Bureau of Labor Statistics (BLS) in 2015 [15][22], MSDs cases accounted for 33% of all worker injury and illness cases. Nowadays Computer Vision has a continuously growing role in many assistive technologies [12] mainly due to low cost, versatility and low invasiveness of modern cameras that, together with modern Machine Learning techniques allow to get detailed information in real-time and effective way. In this paper we describe the results obtained from the analysis of postural assessment of the dentist during operation based on a multiple markers approach; the main MSDs related to this kind of activity are

- Carpal tunnel syndrome
- Tendinitis
- Rotator cuff injuries (affects the shoulder)
- Epicondylitis (affects the elbow)
- Trigger finger
- Muscle strains and low back injuries

In particular we focused our research on how two different visual aids: Medical Loupes (ML) and Surgical Microscope (SM) impact on postural ergonomics with respect to the Naked Eye (NE) during operations. We considered 30 extractions of lower wisdom teeth (38 (Left) and 48 (Right) Mandibular Third Molars). Ten extractions were performed per each considered configuration: 10 with ML, 10 with SM and 10 with NE; 15 of these operations were on the left mouth side and 15 on the right one. Our aim was to track the postural evolution of the dentist's backbone, neck and head during the whole operation and to evaluate the ergonomics during the whole operation. Since the dentist is seated during the whole operation we focused our analysis on the upper limb investigating the probability for the dentist of long-term work related disorders [13].

2. The previous work

A well-established set of criteria to evaluate upper limbs posture during working activity is denominated RULA (Rapid Upper Limb Assessment)[14]. The RULA approach uses diagrams of upper body posture and three scoring table to provide evaluation of the exposure to risk factors. The risk factors considered in the complete formulation of the pioneering work of McPhee [14] are:

- number of movements,
- static muscle work,
- force,
- work postures determined by the equipments and furniture,
- time worked without a break.

which represent the *external load factors*. McPhee also introduced additional elements which influence the load and that vary between individuals:

- the work posture adopted,
- unnecessary static muscle contraction.
- speed and accuracy of movements,
- duration of pauses taken by the worker.

Some further aspects, related to the *individual's response*, are identified by McPhee as *corrective load factors*, he, in particular, identified:

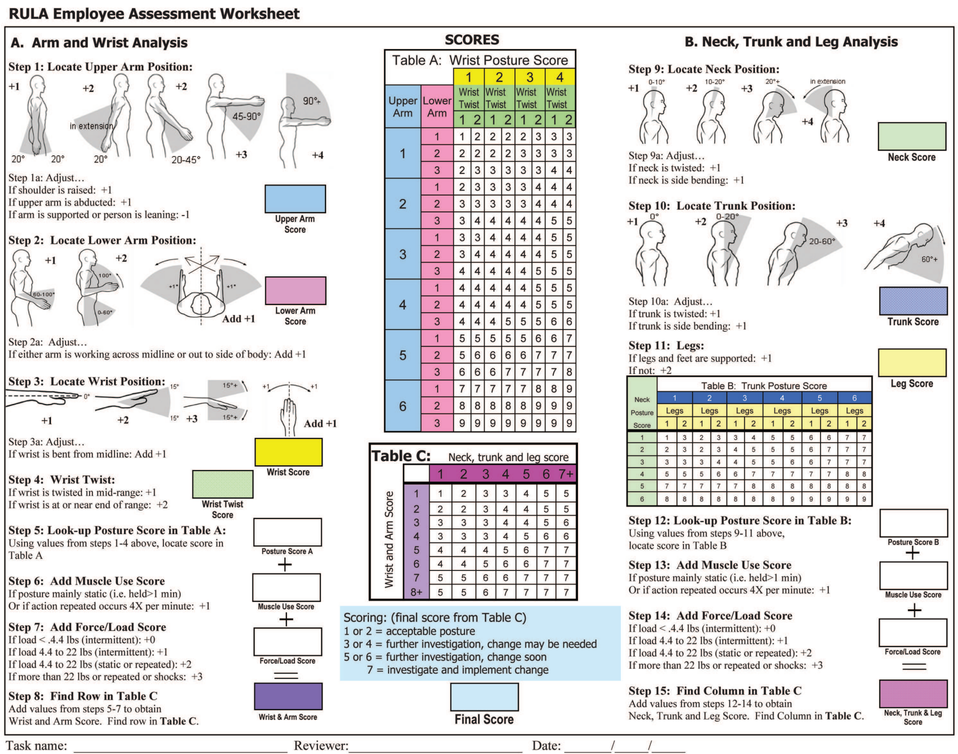
- age,
- experience,
- workplace environmental factors
- psychological variables.

However, also according to [2][3] [1] the *external load factors* are largely the most relevant in terms of risks for long-term MSDs. The RULA method was designed in order to perform a rapid evaluation without the need of special equipment providing the opportunity for a number of investigators to be trained in doing the assessments without additional equipment expenditure but just a clipboard and a pen; RULA was specifically designed for the urgent requirement of the UK Government issued with the UK Guidelines on the prevention of work-related upper limb disorders under the Health and Safety at Work Etc. Act [21] [9]. In fig. 1 a typical RULA Worksheet is reported; different scores are attributed to different aspects like angles between limbs, duration of static postures, values of applied force or moved load.

Even if the RULA method is one of the most commonly used in industrial environments its results are based on the subjective evaluation of angles and postures performed by an investigator from a direct observation or from a movie. Some other approaches have then be proposed in order to improve RULA inaccuracy, a set of them is based on integrated graphic design tools, where a digital human model (DHM) is integrated with the 3D product-process design environment; NERPA (Novel Ergonomic Postural Assessment Method) is an example [18]: based on a complete 3D CAD simulation, it synthesizes the activity sequence in a virtual environment, allowing to address the functional performance of the parts. This approach is based on the theory of Chaffin [4] that affirms that introducing digital human models that enable the study of product and process adaptation for people without any need of physical prototypes can reduce the development time and costs. The effectiveness of this approach was then confirmed by successive studies [8], [11]. However, apart from different analysis methodologies, the RULA criteria and parameters are the widest adopted ergonomics technique. Using the RULA worksheet, the evaluator will assign a score for each of the following body regions: upper arm, lower arm, wrist, neck, trunk, and legs. After the data for each region is collected and scored, tables on the form are then used to compile the risk factor variables, generating a single score that represents the level of MSD risk as outlined in fig. 2

3. The proposed approach

In our specific analysis, we are considering the activity of a dentist during a dental operation, in this case no load transfer or wide and rapid motions are involved and the main issues are related to static postures. Considering the RULA Assessment Worksheet in fig. 1 the most relevant postural issues are related to: frontal rotation, twisting and side bending of the neck and of the trunk. Furthermore during the operation dentists usually held a static position for a long period ($> 1min$) which, according to RULA Work-



RULA Employee Assessment Worksheet

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:
+1 20° 20°
+2 in extension 20°
+2 20-45°
+3 45-90°
+4 90°+

Step 1a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 2: Locate Lower Arm Position:
+1 60-100°
+2 100° 0-60°
Add +1

Lower Arm Score

Step 2a: Adjust…
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:
+1 0°
+2 15° 15°
+3 15°+ 15°+
Add +1

Step 3a: Adjust…
If wrist is bent from midline: Add +1

Wrist Score

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A
+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>1 min)
Or if action repeated occurs 4X per minute: +1

Muscle Use Score
+

Step 7: Add Force/Load Score
If load < .4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score
=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain
Wrist and Arm Score. Find row in **Table C**.

Wrist & Arm Score

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	1 Wrist Twist 1	1 Wrist Twist 2	2 Wrist Twist 1	2 Wrist Twist 2	3 Wrist Twist 1	3 Wrist Twist 2	4 Wrist Twist 1	4 Wrist Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C: Neck, trunk and leg score

Wrist and Arm Score	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Final Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:
+1 0-10°
+2 10-20°
+3 20°+
+4 in extension

Step 9a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 10: Locate Trunk Position:
+1 0°
+2 0-20°
+3 20-60°
+4 60°+

Step 10a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above,
locate score in Table B

Posture Score B
+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>1 min)
Or if action repeated occurs 4X per minute: +1

Muscle Use Score
+

Step 14: Add Force/Load Score
If load < .4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score
=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain
Neck, Trunk and Leg Score. Find Column in **Table C**.

Neck, Trunk & Leg Score

Task name: ______________ Reviewer: ______________ Date: ____/____/____

Figure 1. RULA Employee Assessment Worksheet

Score	Level of MSD Risk
1-2	negligible risk, no action required
3-4	low risk, change may be needed
5-6	medium risk, further investigation, change soon
6+	very high risk, implement change now

Figure 2. MSD risk levels according to the RULA worksheet data

sheet, represents a further risk element. In order to be able to evaluate in an accurate and objective manner the dentist posture we applied a set of markers on the back of a tight T-shirt worn by the dentist during the whole operation that was acquired using a 5 MPixels Gigabit ethernet camera. In fig. 3 it is possible to see the location of different markers on the back of the T-shirt and on the scrub hat.

In literature there are several fiducial marker systems proposed; those based on square markers have gained popularity, especially in the augmented reality community [6][10]. The main reason is related to the opportunity of extracting the camera pose from their four corners, given that the camera is properly calibrated. In most of the approaches, markers encode a unique identification code by a binary code that may include error detection and correction bits [5]. In general, each author has proposed its own predefined set of markers(dictionary) since the number of required markers varies among different applications and, accordingly, the dictionary size. Furthermore, if the number of required markers is small, then a small dictionary with a large inter-marker distance is desirable in order to increase the error rejection in noisy acquisitions. Analyzing different solutions available in literature we chose the

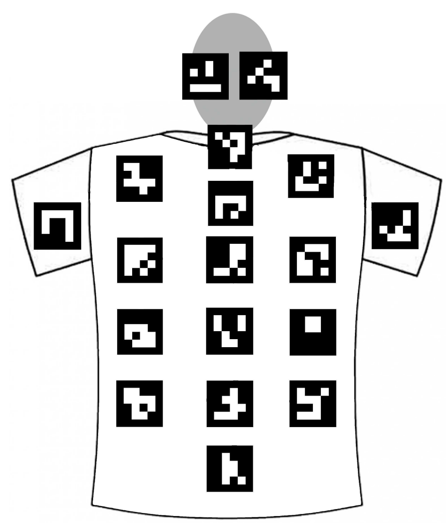


Figure 3. A pictorial representation of the back of the T-shirt worn by the dentist during the operation.

Figure 4. Three examples of ArUco fiducial markers made (from left to right) of 5×5, 6×6, 8×8 bits

Figure 5. A frame of the dentist's back during operation

method proposed in [7] since it fulfills the aforementioned constraints and is also robust to partial occlusions. In fig.4 it is possible to see three examples of markers extracted from dictionaries with different size.

The advantages of such an approach with respect to typical Motion Capture (MoCap) systems, e.g. [19][20] [17] consist in the absence of powered and/or heavy and cumbersome markers like wearable cameras or accelerometers. Furthermore, every single marker provides much more information with respect to approaches based on simple reflective markers since for every marker we are able to accurately estimate its distance from the camera and its spatial orientation, providing us with an estimation of the tangent plane in the marker region.

In fig. 5 we show an acquisition of the dentist's back during operation, two further markers are placed on the surgical cap to estimate the head-backbone angle and two markers, placed on the stool, give a reference of the whole body motion during operation. In fig. 6 all the markers on the back are recognized and properly localized. The reference system of each of them is depicted in figure 6 where the x, y, and z axes are represented by the red, green and blue segments respectively; for further details refer to [7].

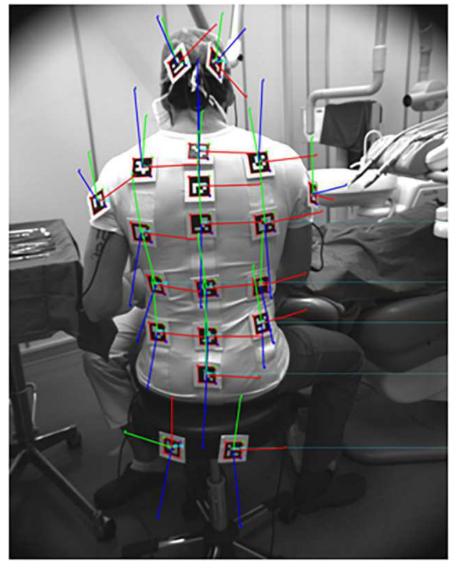


Figure 6. Markers recognized and 3d axes set depicted on the image

4. The global reference system

Since, in the RULA and other evaluation methods the gravity and the angles of different limbs with respect to the vertical direction play a crucial role, its fundamental that all our measures are referred to a global reference system, whose z axis is aligned to the gravity. In order to get this, we acquired a checkerboard on the floor (or placed on a plane parallel to the floor) and assumed its reference system as the global one. In fig. 7 we show the acquisition of the global reference system with the axes superimposed. All the 3D markers are then turned into this reference system: calling $\mathbf{t}_m$ and $\mathbf{R}_m$ the translation vector and the rotation matrix of each marker with respect to the camera frame, and defining $\mathbf{t}_c$ and $\mathbf{R}_c$ the translation vector and the rotation matrix of the reference checkerboard with respect to the camera frame, we can define a global transformation according to fig. 8.

In order to transform all the points into the checkerboard global reference frame we can simply apply the following considerations: A 3D point in homogeneous coordinates, $X = \begin{bmatrix} x & y & z & 1 \end{bmatrix}^\intercal$, can be transformed from the marker reference system into the the camera reference system through equation 1

$$X_{cam} = \begin{bmatrix} \multicolumn{3}{c}{\mathbf{R}_m} & \mathbf{t}_m \\ 0 & 0 & 0 & 1 \end{bmatrix} X = T_{cam} X \qquad (1)$$

Figure 7. The Global Reference System definition based on a checkerboard placed parallel to the ground. The red and green axes (x and y respectively) represent the ground plane while the blue segment represents the z vertical axis

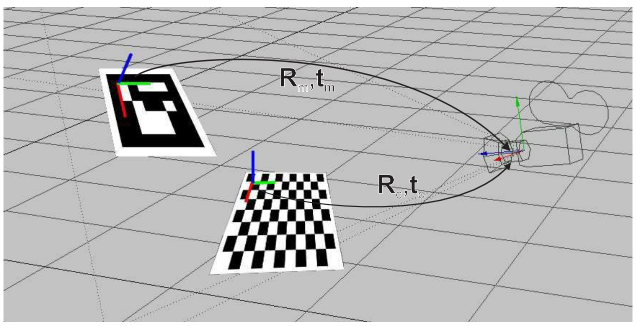


Figure 8. The three considered reference systems: one of the Aruco marker, one of the camera and one of the checkerboard. $\mathbf{t}_m$ and $\mathbf{R}_m$ represent the translation and rotation from the Marker to the camera system, while $\mathbf{t}_c$ and $\mathbf{R}_c$ are the translation and rotation from the checkerboard to the camera system

analogously, moving from the checkerboard to the camera reference system can be done through a transformation T_{check}

$$T_{check} = \begin{bmatrix} & \mathbf{R}_c & & \mathbf{t}_c \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

The whole transform can then be obtained as:

$$\begin{aligned} & X_{check} = {T_{check}}^{-1} T_{cam} X = \\ & = \begin{bmatrix} & \mathbf{R}_c & & \mathbf{t}_c \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} & \mathbf{R}_m & & \mathbf{t}_m \\ 0 & 0 & 0 & 1 \end{bmatrix} X = \\ & = \begin{bmatrix} & {\mathbf{R}_c}^{\intercal} & & -{\mathbf{R}_c}^{\intercal}\mathbf{t}_c \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} & \mathbf{R}_m & & \mathbf{t}_m \\ & & & \\ 0 & 0 & 0 & 1 \end{bmatrix} X \end{aligned} \tag{3}$$

Applying this transform to all the markers in all the acquired frames ($\mathbf{R_m}$ and $\mathbf{t_m}$ change according to different markers and different frames) we are able to track the evolution of the position and orientation of all the markers in a global reference frame where the $z - axis$ is parallel to the gravity vector: This is important since many of the RULA parameters evaluate limbs orientation with respect to the gravity vector. Following the proposed approach we do not have any constraint on the camera that can be placed in a suitable position and orientation to frame the whole operative scene without interfere with ongoing activities.

5. The Analysis Procedure

In fig. 9 we show three simple motion history representations where at every frame the previous markers positions are overlayed with the new one. Such a representation just provides a pictorial representation of what is the dentist's postural evolution while the analysis that we performed is based on a 3D model associated to each marker position. In fig. 11 we provide a representation of our model and in fig. 12 the 3D model is extracted from a single frame: every marker is recognized and the reference system is rotated in order to assign the vertical axis parallel to the gravity while the z-axes of each marker (represented by the orange segments) represent the normals to the considered surface. Since most of MSDs reported in dentistry concern back, neck and shoulders we focused our analysis on the following parameters:

- the neck position with respect to the trunk,
- the trunk orientation with respect to the vertical axis,
- the upper arm orientation with respect to the trunk,
- the twist and bending of the neck and of the back,
- the overall static position of the aforementioned limbs.

Analyzing the neck angle, in order to remove twisting and side bending components we projected all the markers positions in the sagittal plane. The sagittal plane is obtained analyzing the covariance matrix of the positions of the spine markers; following the Principal Component Analysis [16] the eigenvector associated to the smallest eigenvalue represents a vector normal to the sagittal plane. In fig. 10 the sagittal plane is represented where we project spine, neck and head markers in order to estimate postural angles with respect to the sagittal plane. Once angles in this plane are evaluated the twist angles can be estimated analyzing out-of-plane rotations: in particular the twist can be evaluated analyzing the rotation along the eigenvector associated to the highest eigenvalue and side bending can be associated to the rotation along the remaining eigenvector (associated to the mean eigenvaulue). In the following we will focus on the angles in the sagittal plane.

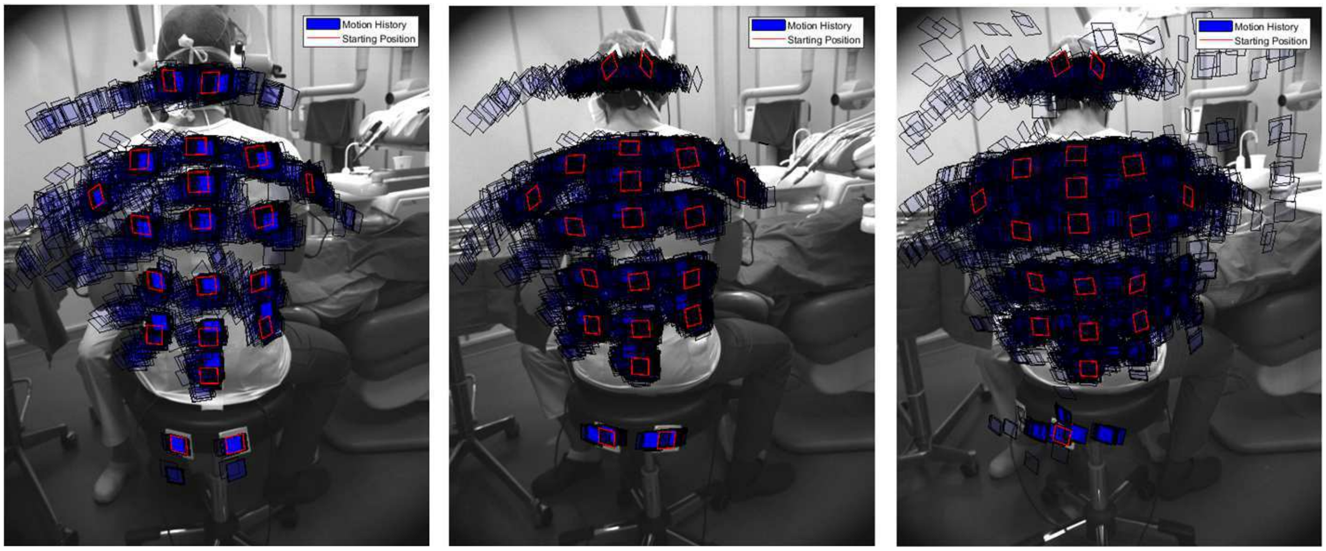


Figure 9. a simple Motion History representation where the position of each marker is simply overlayed to the previous ones. On the left an operation with the SM, at the center one with the ML while on the right an operation with NE. It can be seen the increasing average motion from left to right image.

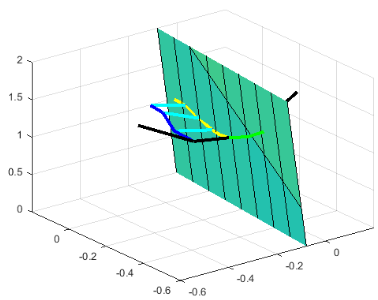


Figure 10. A representation of the sagittal plane extracted from the spine markers

6. Results

As indicated in section 1 we analyzed 3 different configurations: naked eyes (NE), Medical Loupes (ML) and Surgical Microscope (SM).

In the following we describe the procedure in order to monitor the neck-spine rotation: The angle in the sagittal plane is analyzed in the three aforementioned configurations, for operations on the right mouth side and the results are reported in fig. 13. In this figure we superposed the three histograms representing the occurrences of different neck angles during SM, ML and NE configurations for each of them we analyzed 5 operations on the right mouth side. The same analysis, performed on the left mouth side, is reported in fig. 14. As can be seen from these results its clear that the average neck frontal bending when using the SM is lower (more than 20°) with respect to the ML and much lower (about 27°) with respect to the NE. This is reflected in the RULA Worksheet Step 9 (see fig. 1) in an increase of two points in the RULA risk evaluation for the ML and NE with respect to the SM.

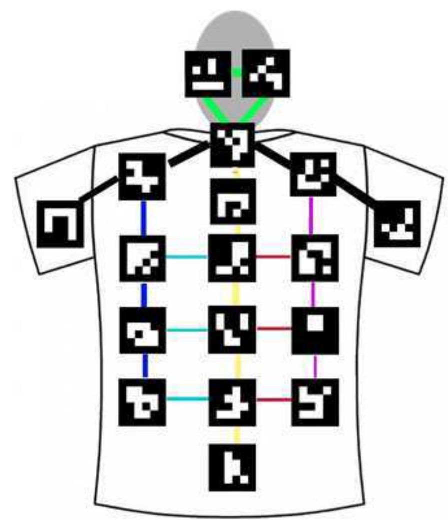


Figure 11. The 3D model that we adopted in our analysis based on the markers positions.

7. Conclusions

In this paper we presented a novel approach for upper limb posture assessment based on the tracking of a set of planar markers placed on the clothes of the worker. Thanks to this non-invasive approach we are able to follow the 3D position and orientation of all the limbs involved in a specific activity during the job execution. The analysis that

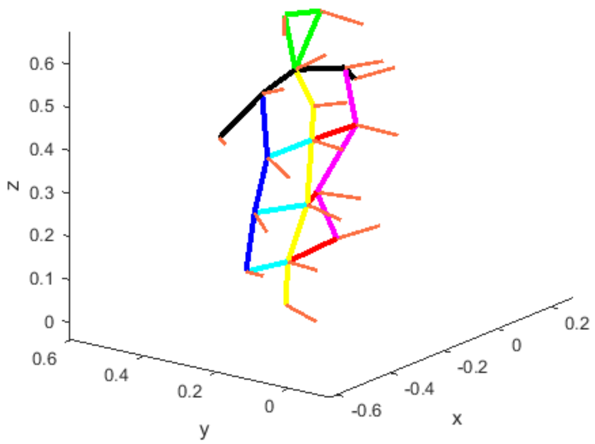


Figure 12. The 3D model extracted from one frame. The orange segments represent the surface normals, i.e. the z axis of every marker.

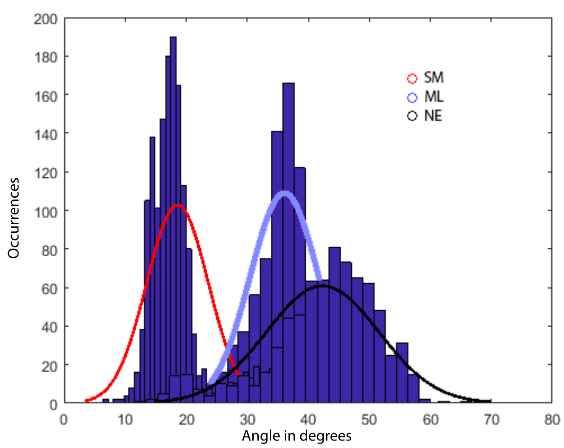


Figure 13. superposition of the three histograms representing neck-spine angles in different operations configurations and the relative gaussian fitting. The considered operations are on the right mouth side. The red gaussian represents operations with the Surgical Microscope, the blue one operations with the medical Loupes and the black one operations with naked eye.

we performed can be easily integrated into classical ergonomics assessment tools like RULA or NERPA providing an objective methodology that does not involve an operator in a subjective interpretation of the monitored job. We applied the proposed approach on operative dentistry comparing the postural impact of different tools used to perform the same operations: extraction of lower wisdom teeth using a Surgical Microscope, Medical Loupes or simply Naked Eye. Thanks to our analysis we found that the usage of the surgical microscope greatly reduces the neck frontal bending and the overall angle between the head and the spine with respect to the naked eye operation while the usage of

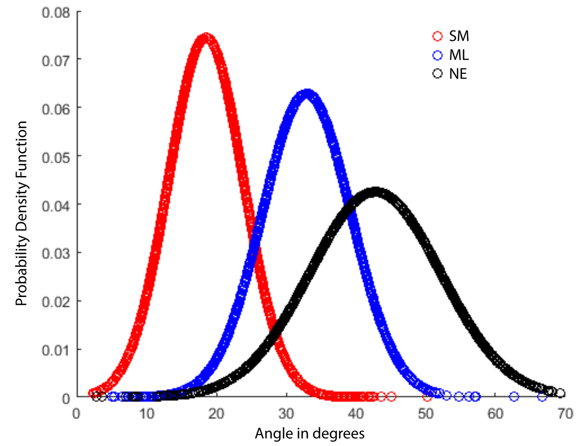


Figure 14. Distributions of the neck rotation with respect to the spine in the sagittal plane fitted with a gaussian distribution. The considered operation are on the left mouth side. The SM involves a much lower average angle with respect to ML that is still lower with respect to the NE. The variance of the SM is also lower than the one of the ML and NE indicating a more stable configuration.

the medical loupes placed in the middle between microscope and naked eye. According to the aforementioned ergonomics assessment tools we demonstrated that the usage of the microscope has a significant impact in the reduction of the long-term Musculoskeletal disorders risk, at least in the neck-spine regions. We believe that the presented approach can find useful applications in many other fields of ergonomics providing the investigator with an objective and effective tool to assess postures of different jobs.

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