DIGITAL HUMAN MODELS (DHM) TO SIMULATE MEAT PROCESSING TO PREVENT WORK-RELATED MUSCULOSKELETAL DISORDERS (WR-MSDs)

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ABSTRACT

Work-Related Musculoskeletal Disorders (**WRMSDs**) are the leading cause of Occupational Disease in working populations of the advanced industrialized countries.

The professional pathology of the upper limbs, from the 80's until today, is continuously increased to represent more than 50% of all occupational diseases.

In literature many tools are available to perform the ergonomic assessment of the workplace.

These tools and methods are classified based on the type of analysis that are able to perform and on the results that can provide.

Beside the traditional methods of assessment, based on tabular theoretical methods, that commonly adopt paper check lists that refer to the main methods of analysis (NIOSH, OCRA, Snook & Ciriello, etc..), are available computer tools performing the same analysis, or, much more appropriate when it needs to make a more accurate biomechanical analysis.

These methods provide numerical value indicating the level of risk to which workers are exposed.

Keywords: WRMSD, Digital Human Model, Health and Safety Simulation Models, Ergonomics.

1. INTRODUCTION

Traditional methods of assessment, based on tabular and theoretical methods, that commonly adopt paper check lists that refer to the main methods of analysis (NIOSH, OCRA, Snook & Ciriello, etc..), are typically used to assess the risk of the workplace, unfortunately not in a preventive way, but once the operator is already playing activities.

To perform this evaluation, you must go beside the workstation, collect all information necessary for the analysis (times, weights, duration, frequencies, tenure, etc.), sometimes shooting movies or photos.

The analysis of collected data allows to determine the index of exposure of the worker/workplace, but do not support the opportunity to evaluate what are parameters values that cause the score of the exposure level to be off the recommended ranges.

These methods do not indicate how the level of exposure can be correct by the introduction of changes in the organization of the workstation or in the working style of the operator.

To achieve this goal, you need to re define values of parameters in the new configuration of the activity for a new analysis, according to the subjective competencies of the analyst.

This takes a long time and does not allow the relationships between different parameters to emerge.

In addition to the traditional methods, there are some models of biomechanical systems that allow to perform simulation in a quite simple, but quasi-static, way, using humanoids models.

They are very complex tools, able to perform dynamic simulations of work tasks accompanied by ergonomic analysis, under various methods.

These tools can be extraordinarily useful if adopted since the concept or design phase.

The main limitation of the traditional methods of evaluation, based on check lists, is that they are highly subjective whether if you follow thoroughly the procedure: in most cases the evaluator, that is often an external consultant, tends to underestimate parameters values to shorten scores within acceptable ranges.

For this reason, it becomes necessary to introduce alternative means to assess the risk to overload of the upper limbs.

The sneaky issue is that the workload evaluation is done at a specific time, but physical problems emerges further and along the time.

In last years, thanks to the technological progress, it has become possible to study, since the design phase, whole ergonomic aspects of a workstation, using Digital Human Models (DHM).

Example of these tools are the Human CAD, JACK, RAMSIS or DELMIA.

The use of software, since the planning and design phase, helps to understand dynamics that may lead to possible problems, under the medical point of view, and helps to identify, in a timely, solutions to reduce risk, but, and this is our proposal, they, at least, could help to compare alternative solutions, under the efficiency, feasibility and physical point of view.

These software applications are, however, very expensive, both from a point of view of the purchase cost, both as expenditure of very well trained human resources, as researchers or practitioners or analysts.

This makes them unusable by the majority of organizations.

A big issue in using any of available tools, both computerized or not, is the difficulty of define, based on scientific principles, relationships among the description of the work contents, strength, frequencies, tenure, postures, etc., and the exposure level for a generic, but also defined individual.

In fact, the pre pathological clinic parameters, and their threshold levels, are not definitively known.

So, under this consideration, it is very important to collect, to classify any of related previous studies to base any further study on a larger and validated data base: there are an huge number of papers that deal with this issue, as it is possible observe in the bibliography paragraph, that shows results and considerations on methodologies, instrumentation, physical and biometrical parameters, and on any pre pathological clinical values in the WR-MSDs to support digital simulation and analysis.

2. BIBLIOGRAPHY

With the actual available search engines for papers and scientific works and studies, it is much more easier than just few years ago, to find a very scaring number of papers that discuss about WRMSDs.

In many papers the use of DHM and of Simulation Tools is described, as in Dan Lamkull, Lars Hanson and Roland Ortengren (2009), where a comparative study has done between VR models and real word observations. The case study has been conducted on a Volvo System for manual assembling of automobiles.

On another side, Honglun, Shouqian and Yunhe (2007), consider the use of ergonomics simulation systems to perform studies of ergonomics analysis. An ergonomic virtual human model is built, to keep together, in a unified framework, elements of biomechanics, of physiology, of anthropometrical model, of posture and motion model to apply to virtual prototyping and virtual product development.

De Magistris, Micaelli, Evrard, Andriot, Savin, Gaudez and Marsot (2013), define principles to build autonomous dynamic DHMs, to be used to compare both the real task and simulated ones based on operator/manikin’s joint angles and applied force in accordance with machinery safety standards. The aim was to examine the error of ergonomics simulations of manual assembly tasks, to correctly predict the real outcomes in the plants, and if outcomes originating from ergonomics simulations could be adopted to increase performance of the real system.

Many works studies special devises, methodologies, data collections tools, to acquire field data to define forces, posture angles or configuration assets, sampling strategies, as in McGorry, Chang and Dempsey (2004), where a special wearable wrist devise is used to collect wrist postures. Trigonometric solution permits determination of wrist angular displacement. Moreover, a people sample was defined and the accuracy of the measure has been showed, as a regression was used to determine the slope and intercept of the relationship between the goniometer and the electromagnetic tracking system for the nine subjects who repeated the evaluation, and a paired t-tests was used to define signal values and real angles values. In fact, another huge issue is the statistical approach to process data to outlines scientific information.

Riley, Ballard, Cochran and Chang (1983) faced with the influence of the temperature versus the assembly time performed in an assembly process.

In Fogleman, Freivalds and Goldberg (1993) an ergonomic evaluation of knives shapes used in meat cutting tasks, has done. Knifes of different shapes, and gloves equipped with sensors were used.

Lewis and Narayan (1993) have studied and designed handles for two commonly hand tools as screwdrivers and chisels. A classification of a people samples, divided in percentiles, and also by sex, has been done. Electromyography analysis were adopted to have an objective measure for strength and forces.

Cimino, Longo and Mirabelli (2009), focus on a methodology for the ergonomic effective design of manufacturing system workstations based on multi-measure approach. An approach based on multiple design parameters, DOE and multiple performance measures is defined to achieve an improved accuracy.

In Boenzi, Digiesi, Mossa, Mummolo and Romano (2013), is descibed an OCRA (ISO 11228-3:2007) approach to evaluate a correct break definition with an additional scheduling for job rotation schedules. Models are applied to automotive industry assembly line, and consist in integer programming models with an objective function.

3. DESCRIPTION OF THE ACTIVITIES

3.1. Some Preliminary Consideration

In this paper we present the initial outlines and considerations in using DHM and the related software suite, to model and to analyze meat processing activities, that are activities where workers are dramatically exposed to the risks of musculoskeletal disorders (WRMSDs).

We are carrying on this work in partnership with some firms in the food industry field, where we have observed, filmed and analyzed the whole process, and some phase, particularly.

The software suite is Delmia Human, V5 of the Dassault Systèmes, based on the CATIA 3D ambient.

The basic idea, for the truth, not definitively original, is to develop virtual models, validated and verified based on the comparison with classic and traditional methods of analysis, as OCRA, NIOSH; RULA, already done by some consultant and analysts in last years, to be more effective, timely, efficient and cheaper, since the phase of work activity definition.

Moreover, we are acquiring and collecting physiological and anthropometric data, of course, just for the local district of meat processing, to try to define function relationships among them and probabilistic effect and damage curves for workers.

Human DELMIA allows to reconstruct a digital human models (DHM) that can perform the same operations.

At this step, we have focused on the first workstations of the meat sectioning, where pig thighs are trimmed, deboned and prepared to become hams, a very relevant phase for the profitability, for the MSD relevance.

Meat activities are extremely important in the district of Modena, in an amount that are significant at national level, also.

DELMIA software has allowed us to model completely mannequins that replicate all the features of a human subject, up to the joints of the fingers.

Through the software, it has been possible to reproduce actions performed by employees, and then simulate in 3D environment.

We were interested on biomechanical analysis for the efforts on several articular joints, especially.

In this work, we started to test software tool attitudes and possibility, as the evaluation of simulation of different methods both of pig thighs trimming and both ham boning.

We started observing for many times, with many observers, the activity execution, for many phases, for any operators, with a special care to define a methodology to mark up postural frames and related joint values.

The aim is to use all collected data to rebuild in a virtual simulation environment the process and the activities, and, in the future, to achieve a better accuracy when we will trim and arrange models.

We recorded many videos of the same activities, performed by many distinct operators.

We have started to classify all observed operators acting these kind of job, and to define many anthropometric parameters, as well as performance parameters (frequencies, durations, technique, etc.) in the company, to define the different way to do the tasks, to statistically describe the process, to define all relevant parameters and aspects related to the physical exposure, but, so far, we couldn’t use this data, because they are not yet complete, and not yet completely elaborate under a statistical point of view.

In fact, till now we have been involved and strongly engaged to explore software behavior and potential to face with our planned targets.

To verify and to define ranges for the response accuracy of the software analysis when different modeling of activities were done, with different mapping for postures, more analysts/researchers started to build models in a blind way, without communicating, to measure and to evaluate errors ranges on the analysis sensitivity.

With respect to the part of the work performed on field, we want underline that we, always, have strived to enforce and to promote collaboration with workers, to achieve a better real observations, and, on another side, we are collaborating with firm Occupational Physicians, and with Occupational Medicine Researchers, to identify the most critical situations from the ergonomic point of view, and to identify most relevant activities to focus the simulation on.

We have started remodeling the "as is" situations, relatively to the layout, locations, equipment, etc. to compare the obtained results among distinct configurations. At this phase, we have not had a big attention to verify models adherence to the real process, as the respect of postures, as well as, we have not yet validate models comparing the simulation assets to the real ones, or outlines and scores and to those reported in the risk assessments documents, but we “just” have tested and explored software potentiality.

In fact, our final target is to overpass all the classical approaches that are used just to evaluate the “as is” observed situation, based on table classification for tasks and posture, that are cited as “state of art methods” for any of the law references in many developed countries, as in Italy is the D.Lgs. 81/2008.

These methods, as OCRA, RULA, Snook & Ciriello, etc. are commonly too much subjective, and not useful and proactive in the project phase of workstations, and of tasks definitions, and that, commonly, get the same overall findings and results.

These methods leaves, as improvement strategy, when scores are too much high to preserve workers health, just the opportunity to introduce work breaks, or to reduce frequencies, and to try to practice jobs rotation.

We also are planning to acquire cutting real efforts applied by operators with a “tricked” knife with load cells inserted between handle and knife blade, or by using dynamometric tables where ham could be laid. The second way, likely, is less accurate and complete to read any of the applied forces.

3.2. Tasks Modelling and Software Behavior

In the next figures we show some representations of the software ambient, with snapshots of the layout we considered, and of the activity we considered too.

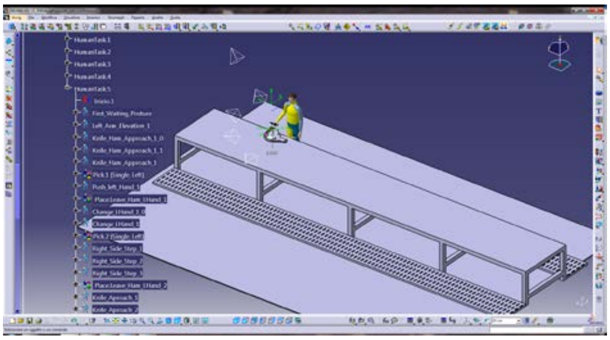

Figure 1: A snapshot of activity layout, of operator/manikin with knife, and of ham

We can observe that there is a table that in the real system is a conveyor, where, on both sides, coming from cold refrigerators storage, thighs, divided in left and right, move ahead, while operators, in a number of eight/ten, execute distinct cutting, and finishing operations.

In the actual situation we have modeled just few operations of the whole number that is required to act this phase.

This is because, the suite we used, that is a best in class suite, both as 3D modeler, both as DHM ambient, to represent and to simulate tasks, layout inter relationship among, work ambient, human issues, activities representation, is very susceptible, touchy, compared to others, that are often simpler but, also, less powerful.

In fact, because it belongs to PLM software, the entire suite can cover quite all of concept, design, manufacturing optimization, layout and work place definition, areas that a product or a product family can require. Moreover, in a very well integrated way, it can supply general CNC code to be used by real manufacturing systems.

Product Lifecycle Management (PLM) is an integrated approach to strategically manage the design, manufacturing, and, also maintenance and end life information for products and services. PLM is supported on computer technologies, but found itself on an integrated approach, and philosophy based on collaborative processes.

PLM access to shared and common information source. It enables the enterprise to extend innovation of product during the entire life cycle, supported on informatics archives and applications reusable several times.

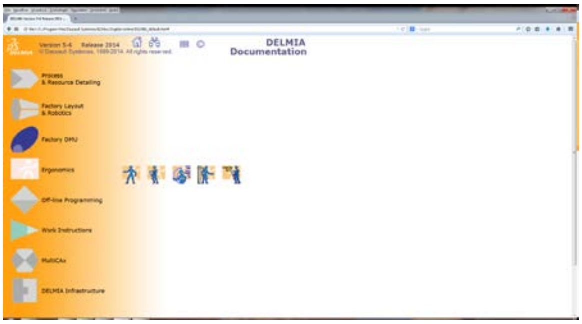

Figure 2: The online guide showing all areas the software can face with: MultiCAx, Factory Layout & Robotics, Digital Mock-Up (DMU), Ergonomics

In the Ergonomics environment, when you model an activity and any of tasks it is composed of, you can rely on many specific "workbenches" specialized to do specific thinks, that you HAVE to activate appropriately.

When, and it happens often, you are wrong to do this, you can get crazy to understand why.

Three persons have started to model all distinct activities of cutting required by thighs, and, up to now, we completed to define the whole approach, and quite all of the four operations needed have been modeled.

Also some cyclical operation, as the sharpening of the knife has been modeled, at least, for one of the distinct way it can be done.

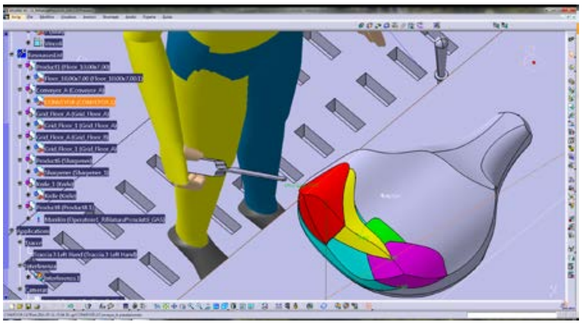

Figure 3: The operator with Analysis colors activated, the modeled 3D Ham, the sharpener and the knife.

In fact, as you can observe in fig. 3, the ham we modeled in the Assembly Design, part of the Mechanical Design workbench, is an assembly of many parts, colored in the figure, that after any cutting and finishing activity, become separated and move on different paths.

The parts that get separated from the ham are six, but someone is processed during the same operation.

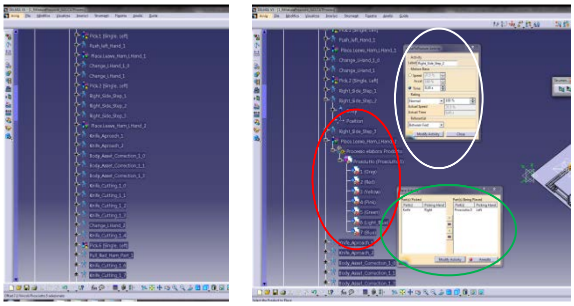

Figure 4: The PPR tree with a list of tasks defined to cut the red part of the ham, and, on right, PPR tree expanded and with configuration windows.

After we modeled first activity, composed of many tasks, we started to test how to perform the promised set of analysis: activating the workbench "*Human Activity Analysis*" from the "*Human Task Simulation*" already opened, where, usually, you are modeling activities, the Ergonomic Tools toolbar become available.

From there it is possible select: RULA, Lift-Lower, Push-pull, Biomechanics Single Action, etc. Analysis icons.

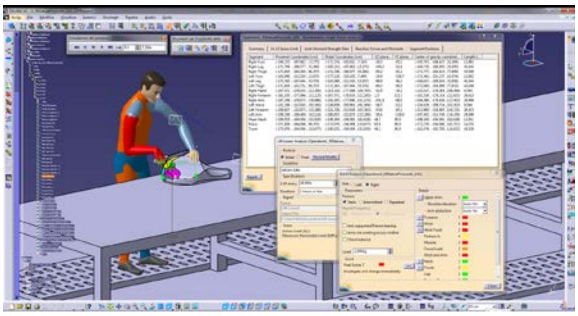

Figure 5: Snapshot of simulation of Red Part Cutting, with some Analysis windows opened.

It is possible produce the analysis you need, starting the activity simulation, with the window of any specific analysis activated: in this way, it's possible observe the updating of simulation and the refreshing of values on windows for any specific analysis.

Is possible to export all data that the software produce during the simulation, with a defined time step.

Moreover, it is possible, at visual level, the activation of coloring on the simulated manikin, when predefined threshold are overpassed. The scale and the type of color can be user defined.

Another thing we were strongly interested to verify, was the opportunity to apply loads or charges to the manikin, over the appropriate weight of parts that are lifted. This interest is because we are, as we told before, planning to acquire all real strength for operators, to be used to feed the model.

We could verify that is possible apply loads to the manikin, define specific values for right and left, specify direction along x, y, z axis.

We started to test the opportunity to fill the field of the load value with formulas, or with table data.

Up to now, on our present experience, it seems possible.

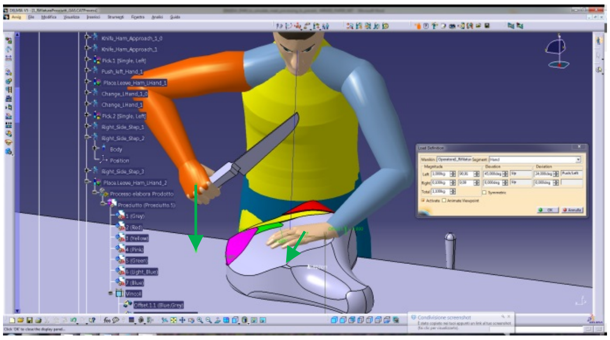

Figure 6: Green arrows represent specific load vectors applied to manikin hands.

Anyway, it is possible change and correct mean values for loads in the analysis configuration, dividing it in more sub parts.

We have verified that in the analysis related to the simulation of the same activity, in any of the suitable analysis methods, the outlines vary depending on the loads values.

We have also compared two different ways to trim hams to define efforts variability and, based on results by simulation, to identify the best solutions, but, no one of the modeled activities has been verified and validated with the real one.

Another consideration to do: any modeled activity goes simulated in a deterministic way, but, when we observe the process, it can vary depending on the operators, depending on the ham characteristics, for the same operator on the specific instance, and so on.

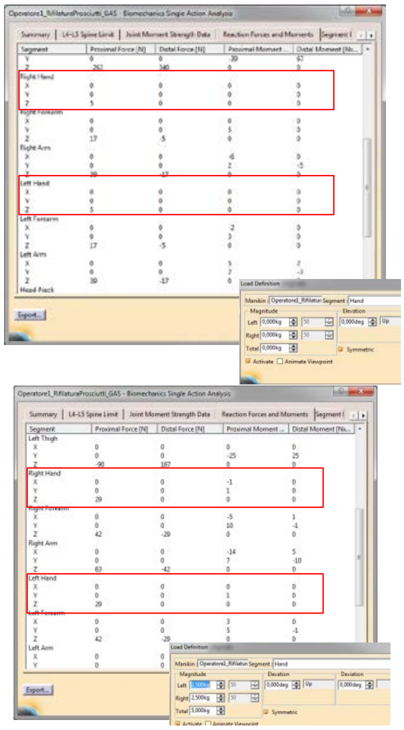

Figure 7: Effects on simulation biomechanical analysis values for two different loads levels.

Then, is very difficult, at the moment, define the "standard" process, and the standard values of the configuration parameters.

The suite we are using do not allow to manage directly this aspect, and a preprocessing phase to define distribution curves for data we are acquiring, needs.

In fact, we are increasing observations to be more accurate in defining the working postures, that we are storing on catalogs, and we are planning to use capture movements tools, also, such as motion capture cams, and systems, available in our Faculty.

Moreover, we are working, in cooperation with Occupational Medicine Researchers, on the identification of the biological and biometric parameters, that can possibly be acquired non-invasively on a sample of workers, in order to identify preclinical data useful to calibrate the digital model.

3.3. Conclusions

In this work we tested the attitudes of a PLM suite to support WRMSDs studies, with a special interest in evaluate the preventive opportunity since the definition phase of the integrated system of layout, work place, activity definition.

Up to now, we have experimented the software behavior, its potentialities and possibilities, and we already modeled many of activities observed in the real contest of a meat processing plant.

In this while, anyway, we have observed, analyzed, filmed many instances of process execution; we have started, in cooperation with Occupational Medicine Researchers, to define and to identify all biological and biometric parameters that can be related to produce clinical and pathological effects on workers, also if under a probabilistic point of view.

Since this is a very ambitious aim, we are interested much more in a definition of comparative opportunity, much more than in to establish absolute effect evaluation, and we are oriented to focus on parameters of both operators, and both of activity configuration, that can possibly be acquired in a non-invasive way, on a defined and available sample of workers, in order to identify preclinical data useful to calibrate the digital model.

We are also developing tools to acquire objective field data, but also subjective ones from workers, from their subjective evaluation of fatigue during the course of activities. But, anyway, we need to proceed on methodological and scientific basis.

Another aim is to feed the model configuration with field data, in a progressively increased automatic way, with the developing of suite software interfaces.

This point is very relevant, especially in the modeling part when the analyst have to define human postures during the work, as when forces have to be defined for the model.

Not often data can be collected with adequate field instrumentations, both for any strength that could be executed by workers, both for biometric values on groups of workers divided in cohorts, that share same particular contest and conditions during a particular time span, and executing the same tasks, with control groups.

Again, in too rare instances, work related factors have been stratified and their effects have been clearly distinguished by infinite others, as is possible with a long term observation, and with the application of adequate statistical test, as the C test, that can follows time series of data.

The effects of the presence or absence of one or more factors should be observed trying to filter effects of other environmental or contingent factors.

For the future we will try to characterize workers for sector with the main anthropometric characteristics relevant to the analysis.

The results shown are the starting point for the work we are doing, at the time, the results are affected in an important way from the method of reproducing working postures.

It is obvious that these are only the first parts of a program that will require much more time to give meaningful results.

This is a first step, and in a short future we will compare our models to the real scenario, and outlines produced by the software to results of ergonomic evaluations of workstations, in the activities of boning hams, carried out with the traditional methods of analysis (NIOSH, OCRA, etc.), in order to identify in a timely with the optimal software workstations to reduce MSDs.

The results are encouraging, even companies involved were very satisfied and encourage us to be hopeful for the future.

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