5 A NEW APPROACH FOR ASSEMBLABILITY ASSESSMENT USING TIME AND POSTURAL ANALYSIS — A CASE STUDY

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This paper explores a new approach to assess assemblability of manual assembly. Assessment of assembly is a prerequisite to optimize an assembly process. Traditionally assemblability is assessed by Design for Assembly (DFA) tools and Time motion studies. However, DFA tools do not usually take into account the influence of human postures whereas time motion studies focus typically on bench work type of jobs. In order to assess the difficulty of a manual assembly process, we must take into account both the static aspects of the job (represented by difficulty of maintaining a posture) as well as its dynamic aspects (difficulties associated with moving from one posture to another). So, we propose a method that combines both time and postural analysis for the assessment of assemblability. The tool used for the static analysis is called Rapid Upper Limb Assessment (RULA); for dynamic analysis we propose a method of time analysis that is based on a ratio of time spent in fine and gross motions carried out in an assembly process. The difficulty of assembly of a series of manual assembly tasks carried out in laboratory was assessed by this method and correlating the assessment with the feedback obtained from the subjects who carried out these assembly tasks. A video recording of the assembly tasks of a desktop personal computer frame assembly was used as the case study. The results show that there exists a significant correlation between the subject feed backs and the combined difficulty scores.

Keywords: Assemblability, Assessment, Ergonomics.

1. INTRODUCTION

Assembly has traditionally been responsible for bulk of the direct labour cost and manufacturing cost. Typically it accounts for 50% or more of manufacturing costs.[1] It is a labour-intensive activity and is carried out manually for complex tasks.Generally while doing assembly, people find some operations more difficult than others. However, it is difficult to identify which factors make some assembly operations more difficult than others. It is also not easy for assembly operators to quantify the degree of difficulty in carrying out a task. Answering these questions should help to reduce assembly difficulties, which induces benefits like reducing the cost of assembling a product, reducing the fatigue of the operators, by improving the quality of the product, etc.

The objective of our ongoing research is to provide appropriate answers to the above questions: how to assess difficulty of assembly, what factors are responsible for this difficulty, and how the above factors cause the resulting difficulty. We believe that no single factor alone contributes to the difficulty of an assembly task. We propose that the factors that affect assemblability can be grouped into five major groups related to (i) part (ii) person (iii) process (iv) tool and (v) environment. While developing an understanding of these factors and their contribution to assembly difficulty are the eventual objectives of this research project, this paper deals with the first question, a prerequisite to answering these objectives: "How to assess the degree of difficulty of an assembly operation or process?"

2. RELATED WORK

Traditionally, assemblability is assessed by using Design for assembly (DFA) methodologies. Some of the well known DFA methodologies are Boothroyd-Dewhurst method, Sturges DFA calculator, The DFA house, Hitachi assemblability evaluation method and Sony DFA method.[1–5] Each of these DFA methodologies helps a designer to identify assembly problems during the early stages of the product development cycle. However, they do not provide much information about the influence of ergonomic elements of the humans who assemble the parts within a product. In assessing manual assemblies, it is essential to take into account human involvement and the problems faced by human operators.

Literature review indicates that manual assemblies are assessed primarily by two methods: *Ergonomic postural analysis and Predetermined time systems*. Two methods have been commonly used to record the postures of a subject for ergonomic postural analysis. Genaidy *et al.*,[6] categories these as *observation based technique* and *instrumentation based technique*, discussed in the next two paragraphs. In observation based technique video recording is used for postural analysis and in instrumentation based technique, devices are attached to a person for the measurement of specific body segment.

McAtamney and Corlett[7] developed RULA (Rapid Upper Limb Assessment) for the investigation of work related disorders of workers. Feyen *et al.*,[8] developed a software tool which integrates 3DSSPP (3Dimensional Static Strength Prediction Program) and AutoCAD for the use in biomechanical analysis. Roland and Forsman,[9] developed VIDAR which uses interactive operator assessment of video recordings for the ergonomic evaluation of manual material handling in automobile workshop. Hignett and McAtamney,[10] developed REBA (Rapid Entire Body Assessment) tool, in which both static and dynamic loading factors, human load interface and gravity assisted upper limb positions are taken into consideration for posture evaluation. Kee and Karwowski,[11] present a new technique called LUBA (Loading on the Upper Body Assessment) which estimates postural loading on the upper body assessment. The RULA software has been used by Massaccesi *et al.*,[12] to study the postures of truck drivers; they claim that this software is suitable for rapid evaluation of loading of neck and trunk. Santos *et al.*,[13] reviewed the use of OWAS software used for ergonomic analysis.

The main disadvantage of the above observation based techniques is that their accuracy is low when compared with the instrumentation techniques. Atha[14] reviews various Instrumentation based techniques for body postural measurement. For example, the movement of the back and skin is measured by strain-gauges whereas joint angles are measured by electrogoniometer. Accelerometer is another tool which is attached to moving limbs for the measurement of tangential acceleration. Generally, these techniques are costlier, more complex than observation based technique and interfere with job processes.

To overcome these drawbacks Keyserling *et al.*,[15] used a checklist to evaluate awkward postures for cyclic jobs which do not uses an observational technique or instrumentation based technique. But it fails to show detailed documentation of work methods to identify the specific job attributes associated with these exposures or provide insights as to how the job could be redesigned to reduce ergonomic stress.

The other method for assessing manual assemblies is by predetermined time systems. Laurig *et al.*,[16] developed a computer aided procedure that uses predetermined motion time systems developed by Gilbreth,(1921) to find motor workload in assembly operations. Laring *et al.*,[17] developed a method called ErgoSAM which identifies biomechanical load conditions of a subject based on the information available in Method Time Measurement (MTM) developed by Maynard et al. (1948). But the use of this method is limited mainly to bench work type jobs.

Literature shows that for fast and easy ways of assessing assembly, researchers used observational techniques i.e video recordings to record the postures that the subject maintain and analyse these either by time motion study or ergonomic analysis tools. Interestingly Desai and Mital[18] evaluated disassembly operations using an analysis that is based on a time scale that combines ergonomic approach i.e. a penalty is given for poor postures while calculating difficulty based on a time scale. However, their method is limited only to disassembly processes of medium sized products which usually are carried out on bench work.

We argue that the existing analysis methods, which are either too specific to certain types of jobs or are based on either static or dynamic aspects of assessment only and are inadequate for reliable assessment of assembly difficulties, which we argue must be generic and based on both static and dynamic aspects of the operations involved. We therefore propose a method which combines both static and dynamic analysis aspects to assess difficulty of an assembly process. We argue that combining the difficulty score of both dynamic (Time study) and static (Posture analysis) methods of analysis will give a much better reflection of the resulting difficulty, and that this must be tested against the feedback on difficulties faced by the users — the assembly operators. Since the user feedback rating is compatible with the use of the RULA software which helps in fast assessment of static, postural difficulty, we have chosen RULA for measuring postural difficulty. We propose a time study in which the ratio of time spent for fine to gross motion is used as a measure of dynamic difficulty. In our proposed study, we defined gross motion as motion in which predominant motion happens at arm level in comparison with wrist level and if the predominant motion happens at wrist level in comparison with arm level then it is called fine motion.

3. METHODOLOGY

3.1. Experimental Setup

Two cameras were used to record each assembly operation. One camera was held stationery using a tripod at a fixed distance of approximately 2 meters from the work area. It was adjusted such that it faced the front side of the table and is kept on the side where the subject was standing, ensuring that 60% of body proportion of the subject was covered. Another camera was a moving one which was used to capture a closer view of subject doing the assembly task. It was handled by the researcher while the subject was performing the assembly task.

In order to establish the method to assess assemblability, video recording of 6 subjects assembling panels on a computer frame was used. The subjects were not supplied with any procedure or sequence with which they needed to perform the assembly. Only the final state of the assembly they needed to achieve was explained to them. Almost all of them followed the same sequence in a similar manner. We decompose the assembly into 6 basic operations. The difficulty involved in each individual operation was assessed. Desai and Mital[18] distinguished operation and task in their work and we followed the same notation as prescribed by them. They argue that each operation (E.g. unscrew) is subdivided into basic elemental tasks (E.g. reach, grasp, align, force exertion, etc.,). It's understood from their argument that operation is a higher set which requires to assembly the product is subdivided into various elemental tasks. The six basic operations that were used in the assembly of computer frame for analysis are listed below. Each operation will have multiple elemental tasks.

1. Fixing the left panel
2. Fixing the top left screw
3. Fixing the bottom left screw
4. Fixing the right frame
5. Fixing the top right screw and
6. Fixing the bottom right screw

Video recording captured by the two cameras were transferred to *Windows movie maker*™ and the required editing (like removal of idle run time, trial runs) was done. Then these video clips were imported to *Video Edit magic* ^{rmTM} software for time analysis as well as preliminary postural analysis where in the postures for each operation were captured.

The analyses were carried out as follows. The assembly of the computer frame was divided into the 6 operations mentioned earlier. The start and end time of each operation was noted for all the subjects. Then each individual operation was divided into 4 frames such that each frame would represent the postures at that instance. So, every operation would have 4 frames or 4 postures from which to calculate the difficulty score. The start of the operation was taken as the first frame, the end of the operation as the fourth frame and two additional frames in-between was captured. All four frames were equally spaced in the time scale such that each operation would have four frames irrespective of the time taken in carrying out the operation. Then these frames were analysed using RULA (Rapid Upper Limb Assessment).

3.2. Ergonomic Postural Analysis

RULA (Rapid Upper Limb Assessment) is a method used to investigate work-related upper limb disorders.[7] The main advantage of this tool is that it does not require any equipment, while providing a quick assessment of the postures of the neck, trunk and upper limbs along with muscle function and the external loads experienced by the body.

In RULA, the body segment angles that a person maintains (i.e., the posture) during a particular instance in an operation are entered. Only the range of body angles, rather than the exact angle, needs to be entered. The advantage of this method is that it gives a single difficulty score for a particular posture. Using this method, difficulty score of all the postures involved in an assembly operation are calculated. If the score is 1 or 2, this indicates that the posture is acceptable if it is not maintained or repeated for long periods. Similarly if the score is 3 or 4, it indicates that further investigation is needed and changes may be required. Score of 5 or 6 indicates that investigation and changes are required soon, and a score of 7 indicates that investigation and changes are required immediately. The angle inputs entered into RULA for right hand, left hand, and other body segments for each posture were assessed by viewing the posture (Figure 2). After the inputs were entered, the output obtained for a particular posture is shown in Figure 3. The difficulty scores and action levels thus obtained are tabulated in Table 3.

Figure 1. Example of various frames used for an assembly operation.

Figure 2. An example posture used for entering input in RULA.

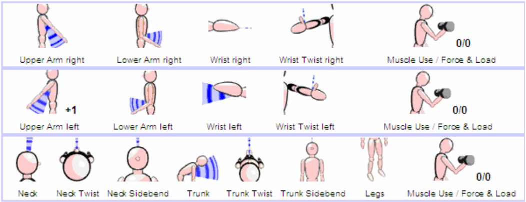

Figure 3. An example output showing entry obtained for various body segments. Source: http://www.rula.co.uk/cgi-bin/rula_calc.cgi

Table 1. RULA difficulty score output used for analysis

Postural difficulty score	Worst case among difficulty score	Recommended action level for the corresponding score
2/2, 2/2, 4/4, 5/6	5/6	3/3
5/6, 4/5, 4/4, 4/4	5/6	3/3
4/4, 5/5, 4/4, 4/4	5/6	3/3
4/4, 3/4, 4/5, 6/6	6/6	3/3
6/6, 5/6, 4/4, 3/4	6/6	3/3
3/4, 4/4, 4/4, 4/4	4/4	2/2
3/3, 3/3, 3/3, 4/4	4/4	2/2
4/4, 4/4, 4/4, 4/4	4/4	2/2
4/4, 5/5, 5/5, 4/4	5/5	3/3
4/4, 2/3, 4/3, 4/5	4/5	2/3
4/5, 4/6, 5/7, 3/4	6/7	3/4
3/4, 5/7, 5/7, 5/7	5/7	3/4

3.3. Time Analysis

We propose that an important indicator of difficulty in an assembly task based on time analysis is the ratio of time spent in fine motion to that of in gross motion. This is based on the argument that jobs that involve fine motion are more difficult to do than those that involve gross motion. We define a gross motion as that in which predominant motion happens at the arm level. If the predominant motion takes place at the wrist level, we call this fine motion. The time spent in fine motion and gross motion involved in each operation time were found out by running the video at a slow speed using Video edit magic^{TM} software, categorising the duration of the operation in terms of fine and gross motion chunks, and adding the time involved in each kind of chunk.

3.4. Feedback Obtained from the Subjects

After the subjects had performed the assembly, the subjects were asked to rate every operation on a scale from 1–5 with 1 for very easy operation and 5 for very difficult operation. This was done by showing to the subjects their respective video and asking them to rate the difficulty. The feedback was obtained at the end of each operation. After the subjects completed rating of one operation, the video was played back again to show the other operations for rating. This process aiding the subject with video helped the subjects in recalling what he/she had done during assembly and thereby giving improved way of rating.

4. RESULTS

The outputs of RULA analysis, time analysis and feedback obtained from the subjects are shown in Table 2. To use any of the metrics, validation is required. We argue that correlation with user feedback is the most appropriate validation in the absence of any other formal criterion available. So we correlated the various metrics with the user feedback as shown in Table 3. The strength of the relations between

Table 2. Various output used for correlation analysis.

Action level by RULA		F/G ratio (c)	Feedback obtained from subjects (d)
Right (a)	Left (b)		
3	3	0.911	2
3	3	4.194	2
3	3	3.325	4
3	3	2.179	3
3	3	3.677	2
2	2	8.739	3
2	2	0.537	1
2	2	3.417	2
3	3	1.91	4
2	3	0.765	1
3	4	5.456	3
3	4	2.135	2

Table 3. Various relations and their calculated correlation coefficients.

S.No.	Relations	Calculated value of correlation coefficients
1	d Vs a	0.346
2	d Vs b	0.491
3	d Vs c	0.360
4	d Vs (a*b)	0.451
5	d Vs (a*b*c)	0.528

different metrics and the user feedback was determined using Spearman's rank correlation. The metrics that need to be compared are very different from one another, and Spearman's rank correlation is the preferred method to check this type of relation.[19] The calculated values are shown in Table 3.

The null hypothesis used was that there is no correlation between the metric under consideration and the user feedback. From table (Source:[19] Refer Table 7, Page 568) the correlation coefficient (r_s) is 0.496 for $n = 12$; $p = 0.1$. Each relation in Table 3 was compared with this value (i.e $r_s = 0.496$) to check its strength. The result shows that the calculated values in all the cases except the fifth case are within the acceptable region of null hypothesis. So, we accept the null hypothesis for the first four relations and reject for fifth case, that is, only the fifth relationship is acceptable (with a level of significance of $p = 0.1$).

5. DISCUSSION

Since the combined way of analysing the difficulty shows good correlation with the user feedback, we conclude that the combined difficulty score based on time analysis and RULA is an acceptable measure for finding difficulty. We therefore conclude that the new method of combining static and dynamic analysis for finding difficulty is a promising technique to assess assemblability. It must be mentioned here that the correlation is tested at significance level of $p = 0.1$, while typically correlation is tested at p = 0.05-0.01 (Source: http://www.introductorystatistics.com/escout/chap_12/ ki_chap_12_s9.html).

We believe that the increase in sample size and real time feed back from subjects will result in better correlation. We need to further validate the result by conducting additional experiments on other assemblies with larger samples. Instead of obtaining feedback from the subjects after they performed each assembly operation, we can obtain it in real time i.e. during the performance of operation itself. This can be done in two ways: 1. allowing the subjects to think-aloud while performing the assembly which might hinder the operation to certain extent, and 2. capturing the facial expressions of the subjects as visual clues to identify moments and therefore related operations of difficulty.

6. CONCLUSIONS AND FUTURE WORK

This work proposes a new technique to assess difficulty in a manual assembly task. This method combines static and dynamic analyses to assess difficulty. The combined method shows acceptable correlation with user feedback. As this metric combines both ergonomics and time in terms of transitional factors, we believe that this will provide a better means to isolate difficult parts of an operation, as well as help associate these difficulties with their sources (Part, Person, Process, Tool and Environment). Our future work will focus on these issues.

ACKNOWLEDGMENTS

The authors would like to thank all the subjects participated in the assembly exercise used in this work. Also, Support from The Boeing Company, USA under contract No. 36011 is gratefully acknowledged.

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