Development of a reconfigurable rig for simulating manual tasks in Automobile manufacturing

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***Abstract*— Automobile manufacturing involves considerable portion of manual processes. Before setting up an assembly line for a model, the manual tasks at each station are evaluated for ergonomics to prevent WMSDs among workers. Conducting ergonomic assessment on an actual assembly line affects regular production, so a separate facility is required. In this study we propose a methodology to design a reconfigurable rig to simulate various manual tasks in a laboratory. We have illustrated its application through two examples.**

Keywords—Automobile manufacturing, Ergonomics, WMSDs, manual tasks, MoCap, experimental rig

I. Introduction

The economic and social impacts of WMSDs (Work-related Musculoskeletal Disorders) are well known [1]. Therefore, industries are trying to improve their workplace ergonomics. Ergonomic assessment may be done at different stages of a product development cycle. In the detailed design stage of a car, it is assessed for feasibility of assembly operations and their potential impact on workers' health and safety. In modern plants, multiple car models may be assembled on a common assembly line. Before every change in the production cycle, the tasks are distributed over several assembly stations and are evaluated for their ergonomics. In the Participatory Ergonomics approach, workers are actively involved in implementing ergonomics knowledge and procedures in their workplace [2]. If implemented properly, This approach has shown improvement in health outcomes of workers [3].

There are several indices for estimating the impacts of manual tasks [4], and the means of their assessment can be virtual, physical or hybrid. Virtual assessment can be done on a computer through DHM (Digital Human Model) simulations. Physical assessment can be done by three means – self-reporting, observation and direct measurement. Hybrid assessment involves use of Virtual Reality (VR) tools while performing the concerned tasks in a constrained environment, like VR headset and Haptic feedback. When Bernard et al. evaluated the differences in the assessments made by these three means, they could not reproduce some maintenance tasks by Virtual and Hybrid means satisfactorily [5]. They also realised that using real parts with trackers is cheaper than their haptic system and provides a more realistic assessment. Besides, available CAD software can only deal with upper body analysis [6]. Virtual simulations by DHMs are good for doing preliminary assessment in a short time but are not sophisticated enough for a realistic assessment. Their output is the behaviour of a static mannequin, which does not take into account the versatility and adaptability of an actual operator who often optimises postures and task performance [7]. Physical validations on real components are necessary because virtual simulations do not always allow the solution of all the typical problems related to workstation-design, like evaluating forces, flexible objects behaviours, etc [7]. In future, assessment by hybrid means in a virtual environment using haptic devices [8] may get cheaper and reliable, but currently the variety of tasks that can be recreated on it are limited. In spite of the availability of virtual simulation tools like DHM and VR, physical assessment on full size mock-ups is still preferable due to saved time and cost on potential re-design work [9].

Traditionally, physical assessment was done by self-reporting and observation. In recent years, direct measurement methods have grown in popularity due to availability of various sensors. Some of the tools used for direct measurement are Motion Capture (MoCap) systems, EMG, HR, GSR, strain gauges, pressure mapping gloves, etc. The apparatus for physical assessment may be an actual manufacturing line, an actual product prototype in a laboratory, or a mock-up in a laboratory.

There are several constraints in performing experiments on actual manufacturing lines like commercial sensitivities, interruption to production, physical constraints on installing sensors, and electromagnetic interference affecting sensor output. Some studies have been conducted on product prototypes of different levels of realism in a laboratory, which is useful for evaluating the design of the product. Sundin et al. worked on a prototype of a vehicle being assembled [10]. Bernard et al. created a physical mock-up to recreate maintenance tasks on the upper deck of a helicopter [5]. Fletcher et al. used a life size model wing box replicating a central section of an aircraft wing mounted onto a jig to capture the physical postures operators need to adopt to perform certain tasks [6]. For evaluating the design of manual processes, a modular mock-up can be a cheaper and more convenient option.

Alabdulkarim et al. constructed a mock cylindrical fuselage as a representative of small aircraft to assess task performance and injury risk [10]. Savino et al created an Oshaped assembly line for automotive components as a test bed, where the operators work on the outside of the line [11]. Garbie designed a jig and used it in the performance of the task on the smart workstation [12]. Kajaks simulated twelve automotive assembly-line tasks in a laboratory setting using sophisticated props and motion capture techniques [13]. These tasks where chosen from a range of work zones in order to represent a variety of reaches. At ErgoLab, the ergonomics laboratory of Fiat Chrysler Automobiles, some of the workplaces of production units have been recreated [7]. Three specific assembly operations were physically reproduced at ErgoLab on the chassis of an automobile, to verify the postures predicted by virtual simulation [14]. An overhead conveyor allowed the rotation of the chassis and the variation of the work height in order to simulate the geometrical features of the assembly line. At the Ergonomics and Variation Analysis Lab (EVAL) of Ford Motor Co. an experimental rig is used for simulation of assembly tasks [15], but its details are not publicly available. From what can be seen, it is built using modular Aluminium profiles. It is also used along with some Virtual Reality equipment to estimate forces involved in manual tasks given certain human postures [16]. We wanted to build a rig for our experiments on similar lines, but could not find any guidelines in literature. Therefore, we propose a methodology for designing and building rigs for recreating manual tasks, as described in the following section.

II. Method

Before making a rig, one should be clear about its purpose, industrial domain, availability of space, tasks to be recreated and other resources used for the studies. The nature of tasks varies with the domain and level of mechanisation in the organisation. In this study, we use a case of an automobile assembly station. Some of the common tasks in automobile assembly are screwdriving, bolt fastening, cable fixing, lifting components and fixing them on the body. Accordingly, some of the commonly used equipment are nutrunners, torque wrenches and tool holders or balancers on workstations.

The design of a rig in a particular domain should be determined by human anthropometry, tasks and postures. These factors are closely related as each task can be performed through a limited set of postures. There are some tasks which can be done only in one way. The aim is to design the rig such that the subjects are compelled to perform a task exactly as they would do on an actual car body. For that, certain physical constraints may have to be inserted in the rig. The rig should also be versatile for recreating a wide variety of tasks, and reconfigurable for doing so in minimal space and with minimum material. Therefore, modular aluminium profiles are ideal for building such a rig. We watched several videos of automotive assembly on Youtube and observed the manual tasks in them. We identified the features of a rig required to recreate each of these tasks, which lead us to document the procedure of designing a rig as follows.

1. Identify the tasks to be simulated. A video recording would be helpful to get a clear idea.
2. Characterise each task as per the framework for knowledge management in manual assembly processes [17]. This helps us understand the equipment used, the environment and the profile of the operator.
3. Analyse the posture/s as observed in the video or as expected, as per the assessment index being used.
4. Design a small rig having constraints and target fixtures just for simulating this task.
5. Repeat the procedure for other tasks.
6. Combine the rigs into one larger rig that incorporates all of their features.

The final rig should have segments, joints and platforms. Each segment is labelled as horizontal, vertical or slant with a number. The segments are made of square or circular section aluminium profiles with grooves on the sides. Some target fixtures can be mounted into the grooves on the segments facing any of the four directions. The target fixtures can house the screws, bolts, cables, slots or any features to be operated on. To illustrate the procedure, we have modelled two screwdriving tasks, designed rigs for them and combined them into one rig. The first task involves fastening a screw on the central console of a car's dashboard using a pistol-grip nutrunner [18] as shown in fig.1. Its parameters and relevant features on the rig were identified as follows.

1) Task type: Screwdriving
Part being operated on: Central console of a car's dashboard
Equipment used: Cordless pistol-grip nutrunner [weight, torque, vibration, etc], sockets/bits.
Environment: Car assembly line
Postures:
Neck = Forward bend 0°, Side bend < 30°, Twist 0°
Shoulder = Front raise > 90°
Back = Forward bend < 30° [Sitting with legs outstretched], Side bend < 45°, Twist <30°
Elbow = flex <30°, twist <45°
Wrist = flex <30°, twist <30°, Side bend 0°
Tool Holding Hand = Right
Other hand activity = Yes

Fig.1. Task-1 on the left showing fastening of a screw on the central console of a car's dashboard [18]. CAD model of the rig for task-1 on the right.

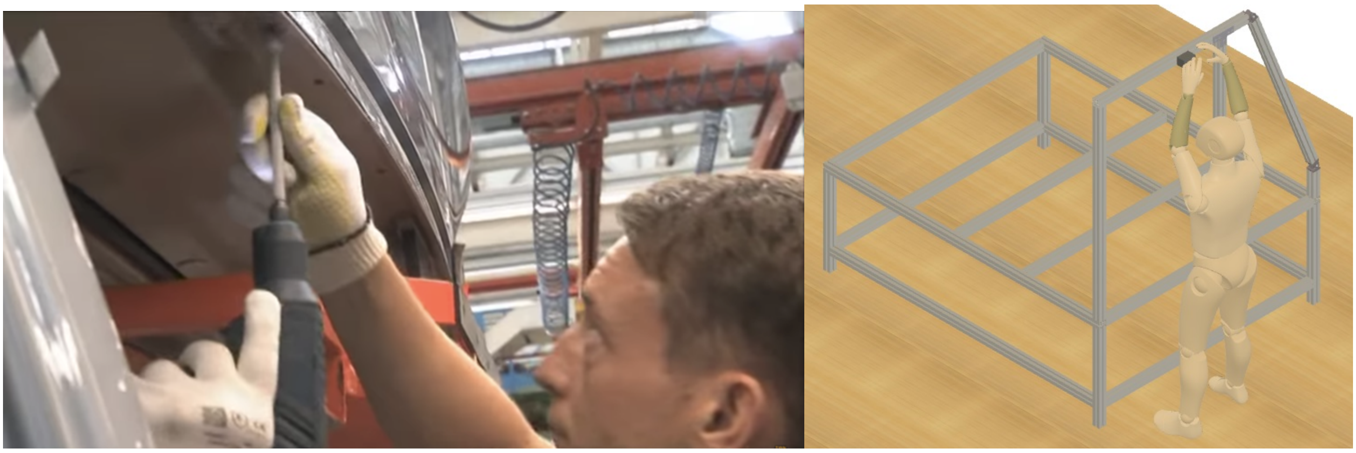

Fig.2. Task-2 on the left showing fastening of a screw under the overhead console of a truck's cabin [19]. CAD model of the rig for task-2 on the right.

The second task involves fastening a screw under the overhead console of a truck's cabin using a pistol-grip nutrunner [19] as shown in fig. 2. Its parameters and relevant features on the rig were identified as follows.

2) Task type: Screwdriving
Part being operated on: Overhead console of a truck's cabin
Equipment used: Cordless pistol-grip nutrunner [weight, torque, vibration, etc.], sockets/bits.
Environment: Truck assembly line
Postures:
Neck = Backward bend <30°, Side bend 0°, Twist 0°
Shoulder = Front raise > 90°
Back = Forward bend 0° [Standing upright], Side bend 0°, Twist 0°
Elbow = flex >90°, twist 0°
Wrist = flex <30°, twist 0°, Side bend 0°
Tool Holding Hand = Left
Other hand activity = Yes

III. Results

The rigs designed for the two tasks were combined into one rig as shown in fig. 3. This rig was designed and modelled in Autodesk Fusion 360 using openly available CAD models of aluminium profiles and joints from MiniTec GmbH. It is composed of ten horizontal segments, six vertical segments and a horizontal platform. The segments are made of square section aluminium profiles with grooves on four sides. Two target fixtures having tapped holes are mounted into the grooves on particular segments as required for the tasks. The constraints for task 1 are afforded by H4, H8, H9, V1, V4 and the platform while its target fixture is on H9. The constraints for task 2 are afforded by H3, H7, H10, V5 and V6 while its target fixture is on H10.

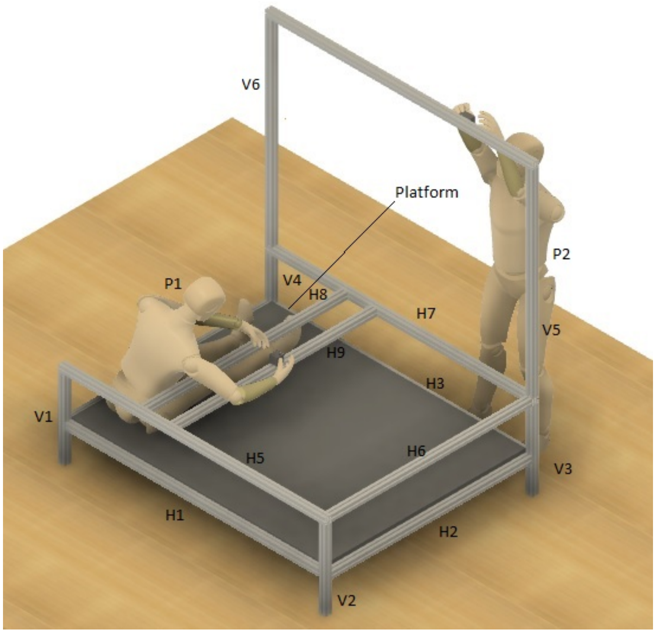

Fig. 3. The experimental rig designed for automobile assembly tasks.

IV. Conclusion and Future Work:

In this study we proposed a methodology for designing a reconfigurable rig for recreating manual tasks in a factory. We illustrated it by designing small rigs for two individual tasks in automobile assembly and combining their features into one rig using a CAD modelling software. Such rigs can enable us to conduct ergonomic assessments of a variety of tasks in a laboratory without affecting the production at the plant. As a virtue of being built from slender Aluminium profiles, such a rig will have minimal visual interference to optical MoCap systems for tracking postures and tools compared to an actual plant. For IMU-based MoCap systems, the electromagnetic interference will be negligible. These factors would help MoCap systems perform more accurately and reliably. Besides, the modularity allows it to be reconfigured for minor variations in tasks and anthropometry. Such a rig can be used not only for automotive assembly, but also for any industry where manual processes are involved such as Aerospace assembly, construction, agriculture, electronics assembly, textiles and food processing. It can also be used for training workers and conducting experiments on AR/VR systems to support assembly processes.

It must be noted that some postures are difficult to enforce as there could be multiple ways of performing certain tasks. The same task can be performed differently by a DHM and by a human [5], and different subjects may do the same task in different ways. In this variation, finding the safest and most efficient way of doing the task can be a topic for further studies, which can also lead to improvement of DHMs.

The next course of our work is to design various target fixtures and their labelling convention. We will then build the rig, test it and validate it by conducting experiments. The rig can be enhanced by adding more types of constraints to simulate more variety of tasks, and sensors to measure more parameters about the tasks.

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