Robot Technology to Support Workplace Ergonomic Adaptation

Jose de Nó*, Pablo González de Santos*

** Dept. Control Automático, Instituto de Automática Industria – CSIC,
Ctra. Camporreal, Km. 0,200, La Poveda, 28500 Arganda del Rey,
Madrid, Spain (e-mail: {jno, pgds}@iai.csic.es)*

Abstract: Workplace safety is a key concern at EU and all developed countries. Figures of work-related accidents show that musculoskeletal disorders are the most common type of occupational illness and construction industry is between the sectors with higher relative cases number. A special purpose robotic system, RoboTab 2000, has been developed with ergonomic requirements in mind that eliminate injury risks in operations installing plaster panels in construction but in transport and removing the system itself.

1. INTRODUCTION

Industrial Robots were conceived to and justified by do repetitive, boring, risky or dangerous tasks for humans and substitute them in the workplace. Automation by robot use in manufacturing heavily increased the productivity and replaced humans in the direct labour positions. Humans and industrial robots never, or rarely, worked hand to hand due to risk of failure of heavy automated machines. In recent times service robots opened in some cases the workplace to cooperation of humans and robots.

New robot generations have to be oriented to new ways of helping humans to improve task execution. Two main basic limitations have to be surpassed in the design of these new robots: heavy weight and mobility. At the same time, robots have to change from totally automatic action to human guided operation. This is a key point if robots or robot-based technology machines have to continue their way to new workplaces (García et al., 2007).

Many task in manufacturing, but mainly in non-manufacturing industries like construction, are not ready to be automated (not enough precision and limited variability, not repetitive, not in the same place) and then cannot be done by robots. But at the same time safety regulations and productivity improvement needs are pushing industries to look for advanced tools and machines to satisfy both requirements. And robotic technology based machines or brand new designed robots can contribute to reach both objectives.

2. INJURY FACTS AND SAFETY REQUIREMENTS AT WORKPLACE

2.1 Risk of Musculoskeletal Disorders

Work-related Musculoskeletal Disorders (WMSD) are defined by the International Commission on Occupational Health as disorders and diseases of the worker musculoskeletal system that have a causal determinant that is work-related. Musculoskeletal Disorders (MSD) are usually produced by awkward postures, repetitive work or handling heavy loads (E-fact 09, 2007) at manual handling operations in the workplace. MSD disrupt work, cut productivity and can lead to sickness absence and chronic occupational disability. Construction industry is particularly sensible to MSD (E-fact 01, 2004) and present many opportunities to introduce robotic solutions to ergonomic problems. Last National Survey of Workplace Conditions in Spain (2007) (Almodovar et al., 2007) shows that musculoskeletal disorders are mainly caused by inadequate attitudes or excessive load weight in manual handling. Also European Agency for Safety and Health at Work (EU-OSHA) reports that MSD are the most frequent problems: 25% of European workers have backache and 23% have muscular pains problems. Key facts for EU-OSHA show that the most affected sectors by exposure to physical risks and MSD complains are Agriculture and Construction and 62% of EU-27 workers are exposed a quarter of time or more to repetitive hand and arm movements, 46% to painful or tiring positions and 35% to carrying or moving heavy loads (Podniece 2008).

In Spain, MSD are the first group of harms at workplace. Statistics of injuries at work shows that 32.4% of accidents are due to overstrain and 87.7% of professional ill health are oseo-mio-articular. Construction and mining workers are the most concerned on heavy load handling (41.5%), use important forces (43.8%) or painful and tiring positions (53.0%) (Villar 2007).

MSD have a high cost to companies and society, direct (insurance, medical, compensation, administrative) as well as indirect (lost productivity). Manual workers are the most at risk from developing MSD. The main factors contributing to the development of MSD in manual handling operations are using force (lifting, carrying, pulling, pushing), repetition of movements, awkward and static postures and others.

2.2 Safety Requirements on Manual Material Handling

All developed countries are very concerned on workers protection and reduction of risks at workplace. In the

European Union the duties of employers, and workers too, to prevent harms of workers are established on European Directives. The most important directives that apply to workers protection are:

- Council Directive 89/391/EEC. It is the “framework” directive that sets out the basic requirements on safety of workplaces.
- Council Directive 90/269/EEC. The Manual Handling directive
- Council Directive 92/57/EEC. It sets out the minimum health and safety requirements for temporary and mobile construction sites.

All of them set out how the employers have to tackle the risks at workplace and for manual handling risks in particular.

Solutions to manual handling problems should address the three main hazards: the weight of the object, the repetitive nature of the operation and poor postures during the operation.

Usually the best solution is the nearest to the top of the following hierarchy of risk control measures, as it will give the best level of control risk:

- Elimination of risk (elimination of the object to manipulate or use alternative operation method)
- Total mechanisation of the operation
- Partial mechanisation: mechanisation of the maximum amount of handling operation
- When it is not possible to eliminate manual handling, workers should be trained in good handling techniques.

To look for the best solutions it is necessary to consider the particular problem even from the design stage of task, operations, machines and parts involved. Due to unstructured work environment in construction industry the total mechanization option to eliminate injury risks is barely possible. The most cost-effective solution is partial mechanization providing workers with task-suited equipment to move, handle, lift, manipulate and dispose heavy parts whatever their position in the workplace were.

Robotic technology is a flexible way of addressing problems, doing that the mechanical structure supports the weight and the engines be in charge of the effort and maintaining the flexibility of human intervention in an unstructured environment.

3. THE PROBLEM

Robotic technology is very well suited to build particular purpose machines to help workers to manipulate heavy components in almost any situation.

Figure 1. Operator disposing a plaster panel

This is the case of indoor installation of prefabricated plaster panels to create inner building walls. Actually common measures of these panels are about 3.0×0.50×0.09 m that makes them hard to manipulate. The difficulty is a lot higher because each weights about 70.0 kg. Panels, packed in groups of 6 are raised to the floor by external crane and positioned horizontally on the floor.

The operator has to lift each panel from the horizontal position in the package to its erect position by rotating it about different axes, paying attention to its dimensions and the ceiling height (not all rotations are possible). Then the operator carries the panel on his back to its final location and positions and orients it by hand (see Figure 1). It is evident that the risk of injuries during all movements is really high and EU Occupational Safety and Health Agency (OSHA) and EU legislation is absolutely clear in these kinds of operations (EU Council 1990).

The operator has to be carefully trained on how to do every movement to achieve the operation and minimize injury risks. This training and the difficulty of replacement of injured personnel implies heavy costs.

Total mechanization of the process is not attainable due to variability of parts and places and unstructured environment, with unpredictable obstacles on the ground. In this kind of problem is where robotic technology may provide a powerful and reliable solution helping the operator do the task without MSD risks. In short, the new robotic tool has to grasp and lift panels from a prone position, stand them up, position and orient correctly and fix in their final place.

3.1Elaboration of Requirements

Manipulator requirements were established after a careful analysis of work operation. This was done jointly by robotic experts and tasks experts in specific meetings and by workplace observation and analysis. Manipulator has to grasp the panel as close to its centre of gravity as possible, to reduce manipulation torques, lift it from a height of about 0.25 m (half the panel width) to 1.50 m and place it about 2 m away.

To position the panel at any position and orientation the manipulator requires at least six DOF, three for positioning and other three for orienting the load. As the installation site is usually more than 2 m long the manipulator has to be easily moved by the operator himself. Also it must be able to be introduced in (and extracted from) buildings under construction through holes of limited dimensions as doors and windows. In order to satisfy all these requirements the robotic system has been conceived as a set of modules, each of them as light as possible and easily and quickly to assemble.

All parts that constitutes the system have to be of limited weight and size to be manipulated by two operators to transport, assembly and disassembly them under safety and health regulations. To comply with ergonomic requirements the manipulator has to be guided directly by the operator, to behave as a tool that eliminate the weight of panels and be handled in a very comfortable posture.

4. PROPOSED SOLUTION: RoboTab 2000

On the above requirements the robotic equipment RoboTab 2000 was designed and built. It is formed by three basic subsystems: frame, manipulator and grasping device plus the control system (Gonzalez de Santos et al., 2003).

The frame is a four caster-wheel platform that supports a column to fix the robotic manipulator. The column is a detachable module. The control system is placed on the platform too. At the upper end of the column there is an electrical cylinder that works as ceiling-grasping mechanism. At the time of work it is extended against the ceiling to fix the platform and prevent any movement and column tumble.

The manipulator has an arm and a wrist. The arm is a three DOF SCARA-type structure because it optimizes the workspace and simultaneously joints 2 and 3 do not directly support the drive load. The first joint is situated directly on the column and parts 2 and 3 are horizontals. In turn, the wrist is based on a differential-parallel mechanism to provide two DOF. The third one is a simple rotary joint. The differential system is configured on a three conical pinion system. With this configuration the wrist motors work at the same time providing the required torques and splitting the effort.

Figure 2: RoboTab 2000 Structure

The grasping device (see Figure 3) is a simple scissors system with manual clasping mechanism. The contact area of each finger is enlarged by a triangular plate that place the contact point closer to the panel central axis.

Figure 3. Grasping device for plaster panels

The manipulator controller is quite simple and is placed on the platform. Motors are controlled by AC drives commanded by PID controllers. They are coordinated by an industrial PC-based computer that also provides the interface with the operator. This interface is maintained particularly simple to facilitate the operator action. It consists of a few switches to select the operation mode, buttons to establish star/stop state and lamps to inform the operator on system status. Figure 4 shows the industrial RoboTab 2000.

Figure 4. Industrial RoboTab 2000

The manipulator is directly guided by the operator using one or two joysticks depending of the manipulator version. In the first version, all six DOF are active and guided through two joysticks (see Figure 5). The right hand joystick is used to control the arm's three DOF and the left hand one is devoted to wrist's other three DOF. This system, really simple, is very intuitive for operators, even the non-trained ones.

Figure 5. Guiding RoboTab 2000a

The second version is even simpler because only the vertical arm joint is active but its weight is internally compensated, the arm's joystick has been suppressed and the two horizontal arm joints are moved directly by the operator action (see Figure 6). On the wrist the yaw joint is passive too. This configuration can even improve the plaster panel manipulation depending on the operator skills.

Table I that follows shows the main features of both versions.

Table I: RoboTab 2000 main features			
		RoboTab-2000a	**RoboTab-2000b**
Payload (kg)		Up to 70	
Dimensions (m)		2x0.7	
Total weight (kg)		150	
Workspace (m)	**Radius**	0.5 to 2	
	Height	0.25 to 1.5	
Frame		4-wheeled platform	
System displacement mode		Pushed by operator	
Degrees of freedom		6 active axes	3 active axes and 3 passive axes
Programming system		Guided	
Speed		0.15 m/s (prismatic joint) 36º/s (angular joints)	

The complete system may be packed in two boxes that contain the mechanical parts and the controller. Each arm joint is independent and all three, the wrist and the grasping device do not weight each more than 5 kg and are assembled by the operator at the workplace, mounted on the frame and connected there with the control system. The assembly time for a trained operator is under 1 hour.

5. RESULTS. LESSONS LEARNED

RoboTab 2000 actually is a prototype supplied to the plaster panel manufacturer (and installer) that has to test it and decide on its use. The expectation with RoboTab 2000 is the complete elimination of Musculoskeletal Disorders accomplishing the risk prevention Directives but to obtain productivity improvements, in the short and long term, too.

To qualitatively evaluate the improvements in risk reduction with RoboTab 2000 we used the MAC: Manual Handling Assessment Charts of UK Health and Safety Executive (HSE, 2003). MAC is useful to assess the risks of three type of handling operations: lifting, carrying and team handling. In this case only the two first have to be considered.

To evaluate each aspect of manual handling operation risk MAC uses a numerical score plus a four colour code: Green (G) = low level risk; Amber (A) = medium level; Red (R) = high level and Purple (P) = very high level of risk. In this case, and for comparative evaluation, only colour code has been considered.

In a deep analysis, the plaster panel installation operation should be decomposed in several movements and each one evaluated separately, but to show the improvements only global operation evaluation is shown in Table II.

Table II: Risk Assessment of operations with and without RoboTab 2000				
	Without		With	
Risk Factors \ Main Operations	**Lift**	**Carry**	**Lift**	**Carry**
Load weight and lift/carry frequency	P	P	G	G
Hand distance from the lower back	R	R	G	G
Vertical lift region	R	NA*	A	NA
Trunk twisting/sideways bending/ Asymmetrical trunk - load	R	R	A	A
Postural constraints	R	R	A	A
Grip on the load	R	R	G	G
Floor surface	A	A	G	A
Environment factors	NA	NA	NA	NA
Carrying distance	NA	A	NA	A
Obstacles in route	NA	A	NA	G

* NA = Not applicable

Figure 6. Operator using RoboTab 2000b

Figure 6 shows RoboTab 2000 in operation. The ergonomic position of arms and trunk is correct and no weight has to be supported by the worker during lifting and carrying operations. Only griping action and movement restrictions by the panel size may present some risks and then are scored rigorously. Obstacles on the floor may be a risk too but it is independent of the tool employed. Anyway, the use of RoboTab 2000 will oblige to have a cleaner floor.

As Table II shows, high level and very high level risks are eliminated and medium level risks are not in critical points and has been rigorously assessed.

Other improvements at the workplace are expected. Time for plaster panel positioning may be reduced but this time will be used to install, assemble and disassemble the robot. The risk of producing damages on the plaster panels during their installation by clashs or drops will be reduced too.

6. CONCLUSIONS

A robotic solution to a particular ergonomic problem in the construction industry has been presented. Robotic technology can easily contribute to modify workplace conditions to achieve ergonomic requirements and satisfy OSH regulations. Joint analysis of workplace conditions by component manufacturers, operators, ergonomic experts and robot designers is needed and the hazards reduction will be very important with enormous costs cut in lost working time, productivity and medical care expenditures. The main drawback is the need to design specific robotic solutions to each problem.

The research group is actually working on more general robotic based technology solutions to ergonomic problems of manipulation in unstructured environments relying on its experience in service robots and walking machines.

ACKNOWLEDGEMENT

This work is supported by the Spanish Ministry of Science and Innovation through Grant DPI2007-65728.

REFERENCES

Almodovar, A., Nogareda, C., Fraile, A., Pinilla, F.J., Villar, M.F., de la Orden, M.V., Zimmermann, M. and Lara, J.M. (2007). *VI Encuesta Nacional de Condiciones de Trabajo*. INSHT, Madrid.

E-fact 01 (2004). Musculoskeletal Disorders in Construction. European Agency for Safety and Health at Work.

E-fact 09 (2007). Work-Related Musculoskeletal Disorders: An Introduction. European Agency for Safety and Health at Work.

EU Council, (1990), COUNCIL DIRECTIVE 90/269/EEC - Minimum health and safety requirements for the manual handling of loads where there is a risk particularly of back injury to workers.

Garcia, E., Jimenez, M.A., Gonzalez de Santos, P. and Armada, M. (2007). The Evolution of Robotic Research. *IEEE Robotics & Automation Magazine*, **14**, 1, 2-15.

Gonzalez de Santos, P., Estremera, J., Jimenez, M.A., Garcia, E. and Armada, M. (2003). Manipulators help out with Plaster Panels in Construction. *Industrial Robot*, **30**, No. 6, 508-514.

HSE (2003), MAC – Manual Handling Assessment Charts leaflet, HSE Books, London.

Podniece, Z. (2008). Work-Related Musculoskeletal Disorders: Prevention Report. EU-OSHA, Luxembourg

Villar, M.F. (2007). Carga Fisica y Trastornos Musculoesqueleticos: Resultados de la VI Encuesta Nacional de Condiciones de Trabajo 2007. *Seguridad y Salud en el Trabajo*, **9**, No 44, 12-24