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A Cooperative Industrial Partner Robot System for Handling Heavy Mechanical Parts in Assembly Lines

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Summary

Recently, industrial robots are widely employed in various fields for automation. However, some assembly tasks still need intervention of human workers, because of the complicated assembly skills involved. In order to assist the assembly tasks, some industrial partner robot have been introduced into the assembly line. These devices are designed merely for supporting the weight of the heavy parts, and sometimes they embarrass the human work from applying their skills. In this research we propose a new system in which robots and human workers cooperate complementarily in an assembly task. This paper describes a prototype robot designed following this idea.

Keywords: Partner Robot, Assembly Lines, Heavy parts

1. Introduction

Recently, industrial robots are widely employed in various fields. In automobile plants, some of them are used in welding processes, painting processes. In electronics industry, many assemblies are completed by them. However there are still some tasks which need intervention of human workers. Since the delicacy required in these tasks is beyond the capability of current robot technologies. In many situations, the difficulty in a totally automatic robotized solution is solved by cooperation between robots and human workers. In current plants, many robots are used for this purpose. They assist human workers making use of their power and precision. Especially, in automobile plants, many such assisting robots are employed. They are used as tools handling heavy parts. With the robots controlled following humans intention a human worker can easily handle heavy parts. This kind of assistance robots has achieved great success [3]. But their functions are limited. Most of them are designed only for supporting the weight of heavy parts. They are not designed for supporting the assembly operation of human workers. During the delicate assembly operations, the human worker can’t get supporting especially if the parts to be handled is heavy.

We propose a new robot system for assisting human workers. The system is aimed to take full advantage of the respective merits of robots and human workers in one assembly task. In the scheme, the robot and human worker cooperate complementarily. They are responsible for completing different parts of one assembly task which they are good at. For example, in automobile plants, sometimes the human worker has to assemble heavy parts following complicated procedure. Under the new scheme, with the robot supporting the weight of the part during the whole assembly process, the worker only perform the delicate assembly operations which are demonstrated as human skills.

The effectiveness of the proposed method is evaluated by introducing the developed partner robot into a practical assembly line which is responsible for assembling a steering post into instrument panel frame as shown in Fig. 1.

This paper is organized as follows. Section I and II present the design of the partner robot. In section III, development of the partner robot following the requirement specification is described. In section IV, control of the partner robot is discussed. Its effectiveness is verified by experiment. The paper ends with concluding remarks in section V.

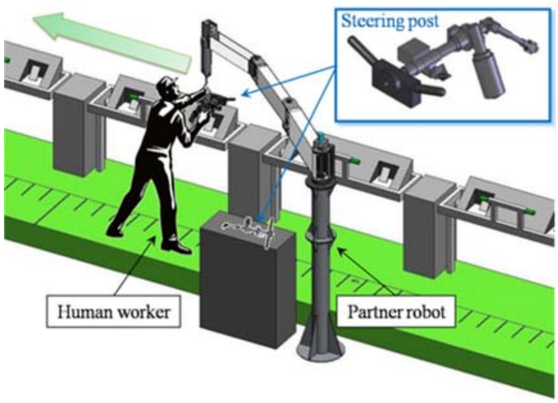

Figure 1. The partner robot in the assembly line.

2. Design of the Partner Robot

2.1 Requirements for Safety

For partner robots which may share common space with human workers during assembly process, the consideration for safety is very important. Actually, the international regulation of “ISO 10218–1” provides a set of safety references for coexisting of human and robot in plants [1]. This regulation specifies detailed technical requirements to the design of the partner robots. According to the regulation, the rated power of the motors used in a partner robot in this situation should be less than 80 watts. Currently, in Japan, fulfilling the regulations is necessary for a robot to obtain an employment license.

2.2 The Targeted Assembly Process

The partner robot designed is aimed to be employed in the assembly process of steering post. It is a practical existing process in automobile plants. During this process, a human worker has to grasp a steering post from parts basket and then fix it into the instrument panel frame. The steering post is a heavy mechanical part. Its mass is 8.5 kilograms. A human worker has to repeat the process for hundreds times in one day. It's a big burden for them. Considering introducing a partner robot in this process to assist the human worker, the assembly process can be summarized as four sequential steps.

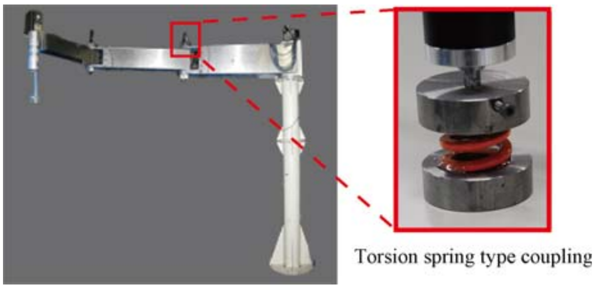

Figure 2. Overview of a partner robot and torsion spring typed coupling.

Step 1: The robot grasps a steering post to be assembled automatically.

Step 2: The robot brings the steering post near to the human worker.

Step 3: The robot supports the weight of the steering post while the human worker completes the assembly. During the period, the robot should be able to move following the human worker's intention.

Step 4: Once the assembly is finished, the robot automatically moves back to grasp the next to steering post for another cycle.

2.3 The Requirements to the Partner Robot

Partner robots should satisfy the following technical requirements.

- The robot has to be safe enough considering possible collision between human workers.
- The robot has to be able to compliantly follow the human worker's movement while assembling phase and it is preferred for this robot to provide functions of direct task teaching.
- Reliable grasping of the assemble parts has to be ensured even though the available grasping position on the object is not located at the center of mass.

We designed the parts and components of the partner robot in order to fulfill above mentioned technical requirements.

3. System Configuration

3.1 Tables and figures

As mentioned above, the power of the motors used in a partner robot which may share common space with human should be less than 80 watts. This regulation makes the designed robot difficult to handle a heavy object in vertical direction. In this research we design the robot as a SCARA robot. The motors employed are used to control the horizontal movement of the robot. And the weight of the steering post is supported by a specially designed passive mechanism. By taking this strategy, we can ensure that heavy parts can be handled by low–powered motors. The developed robot arm has tree links. Their specifications are listed in Table 1.

As for the measures for ensuring safety in possible collision between robots and human workers, we choose the way of implementing mechanical compliance by flexible joints. Actually, there are other approaches which can also realize mechanical compliance. For example, in some researches, ER fluids are used in the detection of contact with a human [4]. And employing pneumatic muscle actuators can also achieve the same purpose as in the work of [5]. The solution employing flexible joints is cheaper and reliable. The flexible joints are implemented by connecting each driving motor to the respective joint with torsion spring as shown in Fig. 2. Encoders are mounted on both sides of motor and joint. Therefore, the encoder reading from motor and joint indicates external force. Employment of these springs also enable direct task teaching which generally necessitate expensive force sensors.

Table 1. Specification of the partner robot

Items	Length, mm	Mass, kg
Base	2 638	84.5
Link1	1 185	32.4
Link2	1 115	17.8
Link3	800	11.3

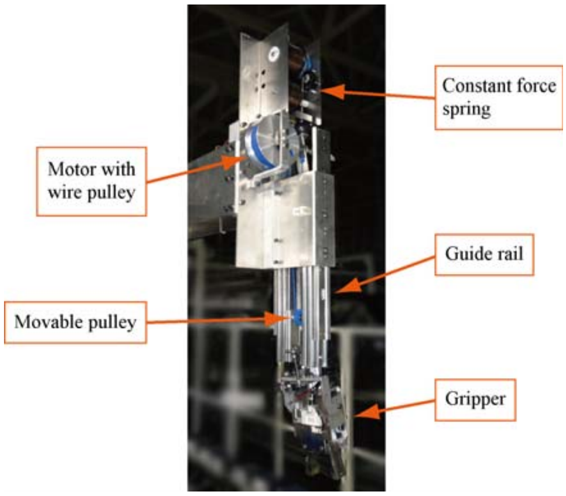

Figure 3. Overview of the gravity compensation mechanism.

3.2 Gravity Compensation Mechanism

In order to lessen the worker's burden, it is important to cancel the load resulted from the weight of the assembly part. It is expected that with the gravity compensation mechanism, a human worker can move the parts in all the directions freely without feeling the weight. In addition, during the assembly the gravity compensation mechanism should not affect the human workers to apply their skills.

The developed gravity compensation mechanism has a constant force spring to generate constant compensation force at any time. With the weight balanced by the constant force spring human worker can freely move the object to be assembled up and down. In this research, the torsion force of the spring is set to the weight of a steering post. The constant torsion spring is winded in two rollers. In addition, in order to prevent its output and from rotating too fast when the external load is released, rotary damper is mounted. The overview of the developed gravity compensation mechanism is shown in Fig. 3.

In the practical assembly line, the developed gravity compensation mechanism should move up and down both automatically and manually when pulled by the worker. We developed an up–and–down mechanism which uses a movable puller to achieve this purpose. A motor and the constant force spring are connected through a movable pulley. When gripper is moved by the motor automatically, the constant force spring is rolled passively. During the assembly phase, the motor is locked. Then the worker can move the gripper freely. In this case, the half of the weight of the object will be loaded on the constant spring.

The motor is fixed in a case with a worm gear. The motor shaft is connected to the worm. The worm–wheel shaft and the constant force spring are connected through a movable pulley by wire. When the worker moves the gripper manually with the constant force spring functioning, rotation of the motor is balked due to the low back–drivability of the worm gear.

3.3 Mechanism of Gripper

The gripper should not release the gripped parts at any case of mechanical or electrical malfunctions without intension of human workers. In order to prevent unintended falling of the parts, double safety systems of self–holding and interlock functions are equipped. The opening and closing component of the gripper has self–holding functions which can keep position with no additional power supply. The interlock function of the gripper is inactive when the gripped part is released. Unless the interlock function is set to be inactive, the gripper never release the gripped parts. In experiments, the human worker uses a switch to set the interlock to be inactive.

When a gripper grasps a heavy payload in a stable state, large constraint force acts on the grasping point. It requires the gripper to employ a mechanism and actuators to generate the constraint force (generally fiction force for holding the object) as described in [2]. However, if the gripped object is allowed to change its attitude freely in the envelope of the gripper closure, the constraints force for grasping the object can be reduced in many cases.

Inspired from this idea, we developed a non–force closure grasping type gripper. The idea within it is that the gripper will not constrain position and attitude of the gripped object. The object is “hung” on the gripper. This design concept may enable very simple mechanism and in addition in many cases the needed power for constraining the object can be reduced. The center of mass of the steering post used in this research is not located on the grasping point. A tight gripping of it which constrains its position and attitude will necessitate employment of large powered motors while with loose gripping which allow the object’s changing in position and attitude can greatly simplify the design. In practical assembly process, the unconstrained motion degree of the object is manipulated by human workers.

In this research, we developed a bell crank typed gripper. It realizes the idea mentioned above. It uses a bell crank at a finger. Therefore there is no need to employ actuators for opening and closing actions. An overview of the bell crank typed gripper.

The gripping procedure using this gripper is described as follows. At first, the freely swinging L–shaped bell crank waits for the contact with the parts from the vertical direction. After the contact with the parts, the bell crank will rotate and form the constraint square by locking a latch mechanism. The parts held in the constraint square.

4. Control of Partner Robot

4.1 Trajectory Following Control

The trajectory of the robot during the assembly process is directly taught by moving each link to desired position. Since the employment of torsion springs in the joints, the external force acted on the robot can be determined from the difference in the encoders of motor and joints in each axis. Thus teaching by holding the end–effector to each path points is implemented.

The control for playing back the taught trajectory has to consider the flexibility in joints. The trajectory control of such a robot with flexible joints has been discussed in many researches. In this research, this control is considered in joint level and they are implemented independently for each joint with the dynamic coupling between different joints neglected.

For each link, let the angle of motor and that of joint to be denoted as θ_m, θ_j, then the control can be summarized as

$$\dot{\theta}_{com} = \dot{\theta}_{pid} + \dot{\theta}_{grv} + \dot{\theta}_{vib} \tag{1}$$

where $\dot{\theta}_{com}$ is the command for the velocity controlled motors employed in this research. $\dot{\theta}_{pid}$, $\dot{\theta}_{grv}$, $\dot{\theta}_{vib}$ refer to the control components of PID, inclination force compensation, and vibration suppression control respectively.

$\dot{\theta}_{pid}$ is the component designed for make θ_j track to a reference θ_j^{ref} . Let K, D refer to the spring coefficient and damping coefficient of the spring used in one joint. And define δ to be the difference measured from the encoder embedded in motor and joint, then we have,

$$\delta = (\theta_m - \theta_j) \tag{2}$$

The torque τ exerted by the spring can be calculated as

$$\tau = K\delta + D\dot{\delta} \tag{3}$$

Then we can obtain the transfer function as

$$\delta(s) = \frac{1}{K + Ds}\tau(s) \qquad (4)$$

It describes the relation between the torque exerted by the spring and its torsional deflection. Thus in order to generate a target a torque τ^{target} in the joint, it needs to move the motor so that the torsional deflection is δ^{target},

$$\tau^{target} = L_{low}(\tau^{target}) \qquad (5)$$

where L_{low} represent a low–pass filtering processing realizing

the transfer function. The PID control component is defined as

$$\dot{\theta}_{pid} = k_p\left(L_{low}((\theta_j^{ref} - \theta_j) + k_i\int(\theta_j^{ref} - \theta_j)) - (\theta_m - \theta_j)\right) - k_d\dot{\theta}_m \qquad (6)$$

where θ_j^{ref}, k_p, k_i, k_d refers to the reference trajectory, P control gain, I control gain and D control gain respectively.

The second part of the controller $\dot{\theta}_{grv}$ is a feed–forward control component used to compensate the inclination force. Inclination due to the weight in hand is observed in the assembled robot. The torque due to the arm inclination is acted on each joint as disturbance for control. In this research, compared with the disturbance torque, the motors employed are not powerful enough, thus it makes it difficult for the robot to obtain stable and quick response. The control for compensating it is defined as

$$\dot{\theta}_{grv} = k_{grv}(\varphi^{ref} - (\theta_m - \theta_j)) \qquad (7)$$

where k_{grv}, φ^{ref} refers to the inclination force compensation control gain and torsional deflection angle calculated from the inclination model.

Component $\dot{\theta}_{vib}$ is defined as

$$\dot{\theta}_{grv} = k_{vib}L_{high}(\theta_m - \theta_j) \qquad (8)$$

where k_{vib}, L_{high} refers to the vibration suppression control gain and high–pass filtering processing which is used to filtered out the high frequency vibration component from the measured torsional deflection signal. Therefore this control has no coupling with the trajectory following control. It is used to suppress the vibration excited during the assembly.

4.2 Verification Experiments

Assembly experiments have been carried out to verify the proposed approach. We implement the robot in a practical assembly line. It represents the force of pulling its end in different conditions. When there are no assembly parts gripped, it needs a force of 90N in order to pull down its end as indicated by the red curves. However, when the steering post is grasped, it only needs a very little force to pull down its end as indicated by blue line. It implies that, during the assembly, the weight of the steering post can't be felt by the worker. They can pay more attention to assembly.

5. Conclusions

In this paper, we proposed a new typed industrial partner robot. In this system, a human worker and the robot undertake complementary parts of an assembly task which they are good at sharing common work space. The proposed method is verified by practically applying it in an assembly line.

References

1. ISO 10218–1, 2006. Robots for industrial environments – Safety requirements – Part 1: Robot.

2. ISO 14539, 2000. Manipulating industrial robots – Object handling with grasp–type grippers – Vocabulary and presentation of characteristics.

3. Lee. S, Hara. S, Yamada. Y, 2010. A Safety Measure for Control Mode Switching of Skill–Assist for Effective Automotive Manufacturing, *Automation Science and Engineering, IEEE Transactions*, 7(4), 817–825.

4. Nakamura. T, Akamatsu. Y, Kusaka. Y, 2008. Development of Soft Manipulator with Variable Rheological Joints and Pneumatic Sensor for Collision with Environment, *Journal of Robotics and Mechatronics*, 20(4), 634–640.

5. Saga. N, Saikawa. T, Okano. H, 2005. Flexor mechanism of robot arm using pneumatic muscle actuators, *Mechatronics and Automation, 2005 IEEE International Conference*, 3, 1 261–1 266.