

Paper:

Weight-Perception-Based Model of Power Assist System for Lifting Objects

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This paper deals with the design and control of a power assist system for lifting objects based on weight perception. We considered vertical lifting force (load force) as the desired dynamics for lifting objects with the power assist system. Load force consists of inertial force and gravitational force. We hypothesized that weight perception due to inertial force may differ from perceived weight due to gravitational force for lifting objects with a power assist system. Based on this hypothesis, we designed a 1-degree-of-freedom (DOF) (vertical up-down) power assist system and determined a psychophysical relationship between actual weights and power-assisted weights for lifted objects. We also determined the excess in the load forces that subjects applied when lifting objects with the system. The excessive load force causes problems such as sudden high acceleration of the lifted object, user safety and other concerns while lifting the object, loss of system maneuverability and stability, and possibly fatal accidents. We modified the power-assist control based on the psychophysical relationship and the load force characteristics. Modifying control reduced the excess in load forces and significantly enhanced maneuverability, naturalness, ease of use, stability, and safety. We proposed using the findings to design industrial power assist systems for transporting heavy objects in various industries such as assembly and manufacturing, mining, logistics and transport, construction, disaster management and rescue, and military operations.

Keywords: industrial power assist system, lifting tasks, maneuverability, weight perception, psychophysics, feedback position control

1. Introduction

User/robot barriers have begun disappearing with increasing robot use in fields such as home automation, industrial production, mining, agricultural production, lo-

gistics and transport, surgery, and rehabilitation. Needs remain, however, for making robots more user-friendly and executing tasks in cooperation with users sharing the same workspace and helping improve work quality, and adjustment, productivity, and safety [1]. Intuitive user/robot cooperation has become a reality instead of a novelty [2–4].

Power assist system is one of the latest types of user-robot cooperation. When a user manipulates an object with a power assist system, the user feels a scaled-down effect of the load and the required forces to manipulate the object also reduce. User's ability to perform physical tasks is limited not by his/her intellect, but by his/her physical strength. The power assist system augments user's ability to perform physical tasks by enhancing physical strength, where the user's intellect spontaneously and centrally controls the command of the system and the resulting user/robot system is superior to a loosely integrated combination of a user and a fully automated system – this is the concept behind the emergence of power assist robots [5, 6].

Although the power assist system breakthrough was conceived early in the 1960s with “Man-amplifier” and “Hardiman” [6], progress remains insufficient. Power assist system innovations are being designed mostly for the elderly and disabled and for rehabilitation [7–10], leaving a lack of suitable power assist systems for manipulating heavy objects in industry.

Though several power assist systems have already been developed for manipulating objects [11–17], these remain insufficiently suitable, safe, natural, and user-friendly for manipulating heavy objects in various industries. The fact is that, acceleration of an object lifted with the power assist system is proportional to the load force (vertical lifting force) applied to the object by the user. User's feed-forward force programming depends on how the user perceives the weight of an object before lifting it [18]. As the power assist system reduces the heaviness of the object, the load force required to lift the object with the power assist system should also be lower than that required to lift the object manually. But, the operator (user) cannot

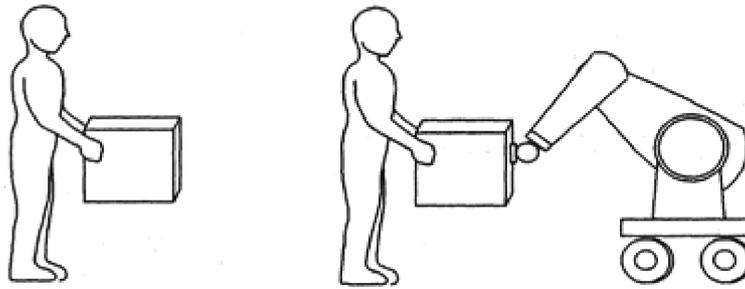


Fig. 1. The human at left lifts an object manually and at right the same object with a power assist robot. When lifting the object manually, the human feels the actual object weight, whereas when using a power assist robot, the human feels a scaled-down portion of weight. Dynamics for lifting objects is load force that consists of inertial and gravitational forces. We hypothesize that, when lifting an object with a power assist robot, human’s weight perception due to inertia may differ from perceived weight due to gravity. This hypothesis means that human must consider mass parameter for the inertial force differing from mass parameter for the gravitational force when lifting an object with a power assist robot because perception and reality for object weight differ. Mass parameters for the inertial force and gravitational force should be less than an object’s actual mass.



Fig. 2. Above from left to right at left, are the fronts of the large, medium, and small PAOs and, from left to right at right, their backs. Two rectangular metal pieces with holes in the center are attached to the inside of the left and right sides of each box. Holes help tie the box to the force sensor.

differentiate between the power-assisted weight (weight of an object perceived by the operator when the object is lifted with the power assist system) and the actual weight (weight of an object perceived by the operator if the object is lifted manually) and eventually applies load force according to the actual weight of the object. As a result, the applied load force becomes excessive and the excessive load force causes problems such as the acceleration of the object suddenly becomes very high, the operator becomes fearful while lifting the object, the object may not be carried to the desired location, the system may lose maneuverability and stability, the system may cause fatal accident etc.

We hold that inconvenience occurs with power assist systems for two reasons:

1. Initiatives have not been taken yet to design specialized power assist systems for manipulating heavy industrial objects.
2. User’s weight perception has not been considered in conventional power assist design and control.

On the other hand, weight perception and manipulative force programming in object manipulation have been very actively studied in experimental psychology, psychophysics, virtual reality, haptics, and cognitive systems.

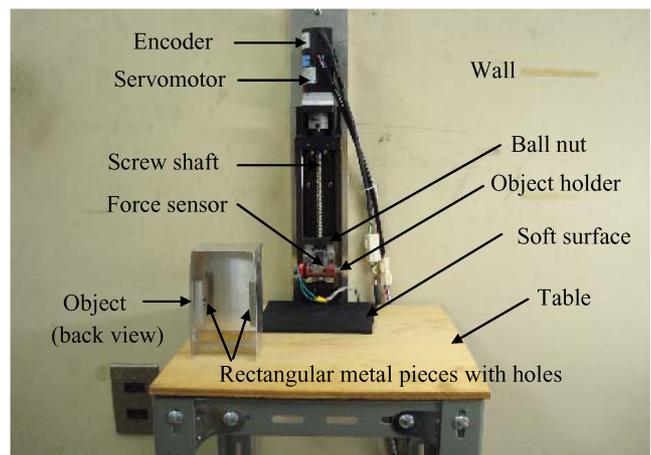


Fig. 3. Power assist components. Note the back of the object (box). Two rectangular metal pieces with holes in the center are attached to the inside of the left and right sides of each box.

A superabundance of reports exists on weight perception and manipulative force programming for lifting objects developed over the last three centuries. Research on weight perception includes visual (optical) perception and haptic perception, which involves tactile perception by touch through the skin, proprioceptive perception by relative position of neighboring parts of the body, and kinesthetic perception by relative movement or motions of neighboring parts of the body. Factors affecting weight perception have been identified together with illusions regarding weight perception [18–26].

Most current research on weight perception and manipulative force programming has, however, been conducted with static objects in either actual or virtual or augmented environments, leaving the actual nature of weight perception and manipulative force programming of dynamic objects in power assisted environment a mystery. We do not see any significant applications of currently available research findings on weight perception or manipulative force programming that solve practical problems or ren-