whether the network can re-optimize through self organization after being subject to a variety of disturbances, ranging from the simple breakdown of a truck to the logistical challenges associated with a major natural disaster (e.g., a hurricane).

Acknowledgements

We would like to thank Robert E. Young for his help and encouragement, and Karthik Gandhir and Rohit Razdan for helpful discussions regarding the possible role of agents in a public logistics network.

References


INTELLIGENT ASSIST DEVICES

H. Kazerooni
University of California at Berkeley
Berkeley, CA 94720
kazerooni@me.berkeley.edu

Abstract

The Intelligent Assist Device [8, 9, 10] is a computer-controlled manual material handling system, which is designed to be used by a worker for repetitive pick and place tasks in various industrial settings, such as distribution centers, warehouses and auto assembly plants. In these assist devices, the operator force on the device is sensed and amplified electronically by use of a computer to drive the device actuator. In other words, the intelligent assist device extends the worker's physical power by adding mechanical power to the maneuvering task. The result is that the intelligent assist device lifts a pre-programmed larger percentage of the total force of the load (gravity plus acceleration) while the operator lifts the remaining much smaller percentage. This smaller percentage is sensed physically by the operator, so the operator has a feel for the load weight and inertia. With the assistance of the intelligent assist device, a worker can manipulate any object in the same natural way that he/she would manipulate a lightweight object without any assistance. There are NO pushbuttons, keyboards, switches, or valves to control the motion of the intelligent assist device; the device computer controls the motion of the device and its load. It has been shown that intelligent assist devices greatly reduce the risk of back injuries when used by workers performing repetitive maneuvers (e.g. depalletizing). This reduction in injury, in turn, will greatly reduce the national cost of treating back injuries.

The author has designed the Intelligent Assist Device (IAD) based on a solid scientific foundation with one goal in mind: minimizing the risk of injuries associated with repeated maneuvers and maximizing the throughput while being robust and user-friendly during repeated maneuvers. The author has evaluated the use of IAD extensively for three applications: warehousing and distribution centers (e.g. Target Stores), auto assembly plants (GM), and delivery services (US Postal Services). The evaluation has been both quantitative and subjective. This article first describes the Intelligent Assist Device characteristics and then gives an overview of its broad applications in various industries.
1 Description

Fig. 1 illustrates an intelligent assist device (IAD). At the top of the device, a computer controlled electric actuator is attached directly to a ceiling, wall, or an overhead crane and precisely moves a strong wire rope with a controllable speed. Attached to the wire rope is a sensory end-effector where the operator hand, the IAD, and the load come in contact. The end-effector includes a load interface subsystem and an operator interface subsystem. The load interface subsystem is designed to interface with a variety of loads and holding devices. In addition to hook shown in Fig. 1, suction cups and grippers are examples of other connections to the end-effector. In general, to grab complex objects special tooling systems should be made and connected to the load interface subsystem.

The operator interface subsystem includes an ergonomic handle, which contains a high performance sensor for measuring the magnitude of the vertical force exerted on the handle by the operator. A signal representing the operator force is transmitted to a computer controller, which controls the actuator of the IAD. Using the measurement of the operator force and other measurements, the controller assigns the necessary speed to either raise or lower the wire rope to create enough mechanical strength to assist the operator in the lifting task as required. If the operator pushes upwardly on the handle, the assist device lifts the load; and if the operator pushes downwardly on the handle, the assist device lowers the load. The load moves appropriately so that only a small pre-programmed proportion of the load force (weight plus acceleration) is supported by the operator, and the remaining force is provided by the actuator of the IAD. All of this happens so quickly that the operator's lifting efforts and the device's lifting efforts are, for all purposes, synchronized perfectly and the load feels substantially lighter to the operator. With this load-sharing concept, the operator has the sense that he or she is lifting the load, but with far less force than would ordinarily be required. For example, for a 50-lb. load force (gravity plus acceleration), the IAD supports 48 lb., while the operator supports and feels only 2 lb.

Fig. 1 shows the end-effector, which was engineered after many years of ergonomic research; it is compact, light, comfortable, ergonomically correct, safe and most importantly, reliable when holding a load. The end-effector reliably measures the operator forces at all times even in the presence of loading and unloading shock forces. This robust end-effector also includes a dead-man switch, which is installed on the handle and sends a signal to the controller via a signal cable. If the dead-man switch on the end-effector is not depressed, (i.e., if the operator is not holding onto the handle of the end-effector), the device will be suspended without any motion even if one removes or adds loads to the end-effector.

The IAD is engineered with variety of embedded safety features. One of the most important safety characteristics of the IAD is that the wire rope does not become slack if the end-effector is physically constrained from moving downwardly and the end-effector is pushed downwardly by the operator. The slack in the wire rope can have far more serious consequences than slowing down the workers at their jobs; the slack line may wrap around the operator's neck or hand creating serious or even deadly injuries. The control algorithm in the computer of the IAD, employing the information from various sensors, ensures that the wire rope will never become slack.

Fig. 1: Intelligent Assist Device.

Gerbel Inc. manufactures and sells in the US and Europe electric-powered IADs equipped with advanced safety features.

End-effector contains a sensor that measures the force that the operator applies to the handle in the vertical direction.
1 Description

Fig. 1 illustrates an intelligent assist device (IAD). At the top of the device, a computer controlled electric actuator is attached directly to a ceiling, wall, or an overhead crane and precisely moves a strong wire rope with a controllable speed. Attached to the wire rope is a sensory end-effector where the operator hand, the IAD, and the load come in contact.

The end-effector includes a load interface subsystem and an operator interface subsystem. The load interface subsystem is designed to interface with a variety of loads and holding devices. In addition to hook shown in Fig. 1, suction cups and grippers are examples of other connections to the end-effector. In general, to grab complex objects special tooling systems should be made and connected to the load interface subsystem.

The operator interface subsystem includes an ergonomic handle, which contains a high performance sensor for measuring the magnitude of the vertical force exerted on the handle by the operator. A signal representing the operator force is transmitted to a computer controller, which controls the actuator of the IAD. Using the measurement of the operator force and other measurements, the controller assigns the necessary speed to either raise or lower the wire rope to create enough mechanical strength to assist the operator in the lifting task as required. If the operator pushes upwardly on the handle, the assist device lifts the load; and if the operator pushes downwardly on the handle, the assist device lowers the load. The load moves appropriately so that only a small pre-programmed proportion of the load force (weight plus acceleration) is supported by the operator, and the remaining force is provided by the actuator of the IAD. All of this happens so quickly that the operator's lifting efforts and the device's lifting efforts are, for all purposes, synchronized perfectly and the load feels substantially lighter to the operator. With this load-sharing concept, the operator has the sense that he or she is lifting the load, but with far less force than would ordinarily be required. For example, for a 50-lb. load force (gravity plus acceleration), the IAD supports 48 lb., while the operator supports and feels only 2 lb.

Fig. 1 shows the end-effector, which was engineered after many years of ergonomic research; it is compact, light, comfortable, ergonomically correct, safe and most importantly, reliable when holding a load. The end-effector reliably measures the operator forces at all times even in the presence of loading and unloading shock forces. This robust end-effector also includes a dead-man switch, which is installed on the handle and sends a signal to the controller via a signal cable. If the dead-man switch on the end-effector is not depressed, (i.e., if the operator is not holding onto the handle of the end-effector), the device will be suspended without any motion even if one removes or adds loads to the end-effector.

The IAD is engineered with variety of embedded safety features. One of the most important safety characteristics of the IAD is that the wire rope does not become slack if the end-effector is physically constrained from moving downwardly and the end-effector is pushed downwardly by the operator. The slack in the wire rope can have far more serious consequences than slowing down the workers at their jobs, the slack line may wrap around the operator's neck or hand creating serious or even deadly injuries. The control algorithm in the computer of the IAD, employing the information from various sensors, ensures that the wire rope will never become slack.

Fig. 1: Intelligent Assist Device.

Gorbel Inc. manufactures and sells in the US and Europe electric-powered IADs equipped with advanced safety features.

End-effector contains a sensor that measures the force that the operator applies to the handle in the vertical direction.
2 The Technological Advances Incorporated Into The IADs

- No Intermediary Control Device
  The IAD does NOT use an intermediary control device like a switch, valve, keyboard, pushbutton or pendant to control the motion of the load. With an intermediary device, the worker has no physical sense of the load and focuses on operating the intermediary device. With the IAD, the operator always has a physical sense of the load, and the load follows the worker's hand in a natural way.

- Load-Sharing
  The IAD and the operator share the load weight and acceleration. The device lifts a pre-programmed larger percentage of the total force of the load, while the operator lifts the remaining smaller percentage. For example, for a 50-lb. load force (gravity plus acceleration), the device can be programmed to support 48 lb., so the operator supports and feels only 2 lb. This programmable load-sharing feature is essential for ergonomically correct load manipulations.

- Adaptive Load Variations
  When using an IAD, the operator does not have to make any adjustments to the IAD to accommodate various loads, because the IAD is adaptive to all kinds of loads, including step-wise variations in loads.

- High Speed
  The IAD can follow a worker's high-speed maneuvers very closely during palletizing and depalletizing operations in warehouses without impeding the worker's motion. The adaptive speed variation of the IAD is one of the important factors in employment of these devices in industrial settings with repetitive tasks. Using a IAD equipped with a set of suction cups, high speed depalletizing with the rate of 15 boxes a minute has been demonstrated.

- Safety Features
  The device is designed with several hardware and software safety layers. For example, if the electric power, computer, sensors, or connectors fail, the IAD will not move. At any time, the operator can also leave the system and system will freeze at its last position. Additionally, the control algorithm in the device prevents any slack in the wire rope from ever occurring. Another important feature of this device is its smooth operation during sudden load drop-off.

- Force Feedback
  When an IAD is used for maneuvering loads, the operator has a physical sense of the movement of the lighter part of the load (e.g., 2 lb. of a 48-lb load). This sense acts as a force feedback on the operator's body to give the operator a feel for the movement of the total load. Research in Haptics and Human-Machine systems has demonstrated that force feedback is an important element for safety during assisted manipulations.

3 Comparison With Conventional Lift Technologies

Balancers, a type of material handling device, consist of a motorized take-up pulley, a rope which wraps around the pulley as the pulley turns, and an end-effector which is attached to the end of the rope. The end-effector has components that connect to the load being lifted. The pulley's rotation winds or unwinds the rope and causes the end-effector to lift or lower the load that is connected to it. In this class of lift systems, an actuator generates an upward force in the rope that is exactly equal to the gravity force of the object being lifted, the tension in the rope balances the object's weight. Therefore, the only force the operator must impose to maneuver the object is the object's acceleration force. This force can be substantial if the object's mass is large. Therefore a heavy object's acceleration and deceleration is limited by the operator's strength. There are two ways of creating a force in the rope so that it is exactly equal to the object weight. First, if the system is pneumatically powered, the air pressure is adjusted so that the lift force equals the load weight. Second, if the system is electrically powered, the right amount of voltage is provided to the amplifier to generate a lift force that equals the load weight. The fixed preset forces are not easily changed in real time and therefore these types of systems are not suited to maneuvers in which objects of varied weights are lifted. This is true because each object requires a different bias force to cancel its weight force. This annoying adjustment can be done either manually by the operator or electronically by measuring the object weight. Unlike the IADs, balancers do not give the operator a physical sense of the force required to lift the load. Also, unlike IAD, balancers only cancel the object's weight with the rope's tension. Moreover, balancers are not versatile enough to be used in situations in which load weights vary, situations, which IADs can easily accommodate (e.g., distribution centers with boxes of different weights).

The second type of material handling device is similar to the balancers described above, but the operator uses an intermediary device such as a valve, pushbutton, keyboard, switch, or teach pendant to adjust the lifting and lowering speed of the object being maneuvered. For example, the more the operator opens the valve, the greater will be the speed generated to lift the object. With an intermediary device, the operator is not in physical contact with the load being lifted, but is busy operating a valve or a switch. The operator does not have any sense of how much he/she is lifting because his/her hand is not in contact with the object. Although suitable for lifting objects of various weights, this type of system is not

Fig. 2: Gorbel's IADs in manufacturing facilities
2 The Technological Advances Incorporated Into The IADs

- **No Intermediary Control Device**
  The IAD does NOT use an intermediary control device like a switch, valve, keyboard, pushbutton or pendant to control the motion of the load. With an intermediary device, the worker has no physical sense of the load and focuses on operating the intermediary device. With the IAD, the operator always has a physical sense of the load, and the load follows the worker's hand in a natural way.

- **Load-Sharing**
  The IAD and the operator share the load weight and acceleration. The device lifts a pre-programmed larger percentage of the total force of the load, while the operator lifts the remaining smaller percentage. For example, for a 50-lb load force (gravity plus acceleration), the device can be programmed to support 48 lb, so the operator supports and feels only 2 lb. This programmable load-sharing feature is essential for ergonomically correct load manipulations.

- **Adaptive Load Variations**
  When using an IAD, the operator does not have to make any adjustments to the IAD to accommodate various loads, because the IAD is adaptive to all kinds of loads, including step-wise variations in loads.

- **High Speed**
  The IAD can follow a worker's high-speed maneuvers very closely during palletizing and depalletizing operations in warehouses without impeding the worker's motion. The adaptive speed variation of the IAD is one of the important factors in employment of these devices in industrial settings with repetitive tasks. Using a IAD equipped with a set of suction cups, high speed depalletizing with the rate of 15 boxes a minute has been demonstrated.

- **Safety Features**
  The device is designed with several hardware and software safety layers. For example, if the electric power, computer, sensors, or connectors fail, the IAD will not move. At any time, the operator can also leave the system and system will freeze at its last position. Additionally, the control algorithm in the device prevents any slack in the wire rope from ever occurring. Another important feature of this device is its smooth operation during sudden load drop-off.

- **Force Feedback**
  When an IAD is used for maneuvering loads, the operator has a physical sense of the movement of the lighter part of the load (e.g., 2 lb. of a 48-lb. load). This sense acts as a force feedback on the operator's body to give the operator a feel for the movement of the total load. Research in Haptics and Human-Machine systems has demonstrated that force feedback is an important element for safety during assisted manipulations.

3 Comparison With Conventional Lift Technologies

Balancers, a type of material handling device, consist of a motorized take-up pulley, a rope which wraps around the pulley as the pulley turns, and an end-effector which is attached to the end of the rope. The end-effector has components that connect to the load being lifted. The pulley's rotation winds or unwarms the rope and causes the end-effector to lift or lower the load that is connected to it. In this class of lift systems, an actuator generates an upward force in the rope that is exactly equal to the gravity force of the object being lifted; the tension in the rope balances the object's weight. Therefore, the only force the operator must impose to maneuver the object is the object's acceleration force. This force can be substantially if the object's mass is large. Therefore a heavy object's acceleration and deceleration is limited by the operator's strength. There are two ways of creating a force in the rope so that it is exactly equal to the object weight. First, if the system is pneumatically powered, the air pressure is adjusted so that the lift force equals the load weight. Second, if the system is electrically powered, the right amount of voltage is provided to the amplifier to generate a lift force that equals the load weight. The fixed preset forces are not easily changed in real time and therefore these types of systems are not suited to maneuvers in which objects of varied weights are lifted. This is true because each object requires a different bias force to cancel its weight force. This annoying adjustment can be done either manually by the operator or electronically by measuring the object weight. Unlike the IADs, balancers do not give the operator a physical sense of the force required to lift the load. Also, unlike IADs, balancers only cancel the object's weight with the rope's tension. Moreover, balancers are not versatile enough to be used in situations in which load weights vary, situations, which IADs can easily accommodate (e.g., distribution centers with boxes of different weights).

The second type of material handling device is similar to the balancers described above, but the operator uses an intermediary device such as a valve, pushbutton, keyboard, switch, or pendant to adjust the lifting and lowering speed of the object being maneuvered. For example, the more the operator opens the valve, the greater will be the speed generated to lift the object. With an intermediary device, the operator is not in physical contact with the load being lifted, but is busy operating a valve or a switch. The operator does not have any sense of how much he/she is lifting because his/her hand is not in contact with the object. Although suitable for lifting objects of various weights, this type of system is not
comfortable for the operator because the operator has to focus on an intermediary device (i.e., valve, pushbutton, keyboard, or switch). Thus, the operator pays more attention to operating the intermediary device than to the speed of the object. This not only makes the lifting operation unnatural, but also limits the operator’s ability to respond to emergency or other unforeseen circumstances arising while the load is being maneuvered. This slow operation has been the major bottleneck in using existing lift devices in high-speed tasks such as palletizing and depalletizing boxes. Many workers, in particular auto and distribution-center workers, prefer to lift loads manually without balancers because they are impeded by the slow and unnatural operation of the existing material handling devices. The difficulty and strain in operating the intermediary control components has forced the workers to abandon existing lift devices in many auto assembly lines and warehouses.

The IAD solves the above problems, because commands are transferred to the IAD via the physical contact forces between the operator and the IAD, eliminating the need for a joystick, pushbutton, or keyboard to transfer such commands. Instead, the operator becomes an integral part of the device while executing the task. In this unique configuration, the worker’s hands, in physical contact with the IAD, exchange both power and information signals with the IAD. Thus, the IAD gives the operator feedback on the forces associated with the load so he/she can adjust to the sometimes unforeseen demands of the situation. Although conventional lifting devices do lift loads, they are limited because they:

- do not give the device operator a physical sense of the lifting maneuver;
- do not compensate for inertia forces;
- do not compensate for varying loads; and
- do not address any key ergonomic concerns.

4 Applications

The IAD was designed with one goal in mind: minimizing the risk of injuries associated with repeated maneuvers and maximizing the throughput while being robust and user-friendly. The IAD has been evaluated extensively for three applications: warehousing and distribution centers; auto assembly plants; and delivery services.

4.1 Warehouses and Distribution Centers

A study on warehousing maneuvers at Target Stores’ Distribution Centers demonstrated that palletizing, depalletizing, loading and unloading trucks and putting boxes on and taking them off of conveyor belts are the most common maneuvers, which also have the highest payback when IADs are used. Initial studies of Target Stores’ distribution centers demonstrated that the objects to be maneuvered in warehouses and distribution centers are mostly boxes of various sizes weighing less than 60 lb that require the workers to maneuver them rapidly (some times up to 15 boxes a minute). Cumulative trauma injuries are caused by repetition, poor posture, force, and vibration. Many injuries in distribution centers are caused by lifting, overexertion, throwing, holding, carrying, pushing, and/or pulling objects weighing 60 lb. or less [1-7]. In a 1984 study of 2700 warehouse workers who were injured at work, 64% of the workers were manually lifting, carrying, or handling an object at the time of injury. 90% of these workers stated that forklifts and similar devices could not have been used to maneuver the object; 20% said that the workspace was too small for a forklift or similar device. Most of the injured workers said that lifting/handling equipment was unnecessary or too much trouble to use. IADs are designed to prevent such injuries in warehouses where moderate-sized loads must be moved in small spaces at a high rate.

The use of the IADs in warehouses has considerable impact on reducing injuries to the worker population because of the great number of warehouses and thus warehouse workers. Fig. 3 (top) shows the use of the IAD in distribution centers during depalletizing operation. Fig. 3 (bottom) shows a worker during manual depalletizing operation.

4.2 Auto Assembly and Manufacturing Plants

Studies of auto assembly maneuvers revealed that the installation of batteries, gas tanks, bumpers, instrument panels, exhaust pipes and prop shafts are important maneuvers that would benefit from IADs. Various load interface subsystems must be employed for connection to various auto parts. The IAD’s have been extensively evaluated at GM Tech Center under the supervision of Dr. Kazerouni (Berkeley) and Dr. Akella (GM) for maneuvering car batteries. The evaluation was both quantitative and subjective. In a set of experiments, the IAD performance was evaluated against the performance of conventional balancer systems manufactured by Scaglia, Zimmerman and Knight. The evaluation method was an experimental study of the dynamic characteristics of the 20
comfortable for the operator because the operator has to focus on an intermediary device (i.e., valve, push/button, keyboard, or switch). Thus, the operator pays more attention to operating the intermediary device than to the speed of the object. This not only makes the lifting operation unnatural, but also limits the operator’s ability to respond to emergency or other unforeseen circumstances arising while the load is being maneuvered. This slow operation has been the major bottleneck in using existing lift devices in high speed tasks such as palletizing and depalletizing boxes. Many workers, in particular auto and distribution center workers, prefer to lift loads manually without balancers because they are impeded by the slow and unnatural operation of the existing material handling devices. The difficulty and strain in operating the intermediary control components has forced the workers to abandon existing lift devices in many auto assembly lines and warehouses.

The IAD solves the above problems, because commands are transferred to the IAD via the physical contact forces between the operator and the IAD, eliminating the need for a joystick, pushbutton, or keyboard to transfer such commands. Instead, the operator becomes an integral part of the device while executing the task. In this unique configuration, the worker’s hands, in physical contact with the IAD, exchange both power and information signals with the IAD. Thus, the IAD gives the operator feedback on the forces associated with the load so he/she can adjust to the sometimes unforeseen demands of the situation. Although conventional lifting devices do lift loads, they are limited because they:

- do not give the device operator a physical sense of the lifting maneuver,
- do not compensate for inertia forces;
- do not compensate for varying loads; and
- do not address any key ergonomic concerns.

4 Applications

The IAD was designed with one goal in mind: minimizing the risk of injuries associated with repeated maneuvers and maximizing the throughput while being robust and user-friendly. The IAD has been evaluated extensively for three applications: warehousing and distribution centers; auto assembly plants; and delivery services.

4.1 Warehouses And Distribution Centers

A study on warehousing maneuvers at Target Stores’ Distribution Centers demonstrated that palletizing, depalletizing, loading and unloading trucks and putting boxes on and taking them off of conveyor belts are the most common maneuvers, which also have the highest payback when IADs are used. Initial studies of Target Stores’ distribution centers demonstrated that the objects to be maneuvered in warehouses and distribution centers are mostly boxes of various sizes weighing less than 60 lb that require the workers to maneuver them rapidly (some times up to 15 boxes a minute). Cumulative trauma injuries are caused by repetition, poor posture, force, and vibration. Many injuries in distribution centers are caused by lifting, overexertion, throwing, holding, carrying, pushing, and/or pulling objects weighing 60 lb. or less [1-7]. In a 1984 study of 2700 warehouse workers who were injured at work, 64% of the workers were manually lifting, carrying, or handling an object at the time of injury. 90% of these workers stated that forklifts and similar devices could not have been used to maneuver the object; 20% said that the workspace was too small for a forklift or similar device. Most of the injured workers said that lifting/handling equipment was unnecessary or too much trouble to use.

IADs are designed to prevent such injuries in warehouses where moderate-sized loads must be moved in small spaces at a high rate. The use of the IADs in warehouses has considerable impact on reducing injuries to the worker population because of the great number of warehouses and thus warehouse workers. Fig. 3 (top) shows the use of the IAD in distribution centers during depalletizing operation. Fig. 3 (bottom) shows a worker during manual depalletizing operation.

4.2 Auto Assembly And Manufacturing Plants

Studies of auto assembly maneuvers revealed that the installation of batteries, gas tanks, bumpers, instrument panels, exhaust pipes and prop shafts are important maneuvers that would benefit from IADs. Various load interface subsystems must be employed for connection to various auto parts. The IAD’s have been extensively evaluated at GM Tech Center under the supervision of Dr. Kazerouni (Berkeley) and Dr. Akella (GM) for maneuvering car batteries. The evaluation was both quantitative and subjective. In a set of experiments, the IAD performance was evaluated against the performance of conventional balancer systems manufactured by Scaglia, Zimmerman and Knight. The evaluation method was an experimental study of the dynamic characteristics of the 20
GM workers in several equal lifting operations using various conventional lift devices and the IAD. During the lifts, the body posture of the worker was recorded from a sagittal view using an active marker motion analysis system. The quantitative experiments resulted in a set of performance data for the IAD. The data showed that to move an object, the IAD has the lowest force-to-speed ratio than any other device (smallest impedance). In other words for a given operator force, the IAD has the highest speed or to move a load at a certain speed, the IAD requires the least amount of operator force. The subjective results are from the questionnaire that the test subjects (GM assembly workers) were requested to fill in after performing the test. Based on the response to the questionnaire, the IAD received the highest mark in terms of “comfort of use”, “ease of control”, “accuracy of control” and “compensation for load variation”.

Fig. 4: Dr. Akella of GM during evaluation of IAD by installing a battery on a truck.

Fig. 5: Figure on the left shows a GM worker wearing reflective markers at his ankle, knee, hip, shoulder, elbow, and wrist during an experiment with a IAD. Figure on the right shows a computer model of the worker that is used to calculate the joint torques and LSS1 force using the force and position measurements.

4.3 Delivery services

Postal services across the world use sacks and trays to hold letters, magazines and small boxes. These sacks and trays, which are handled manually by mail handlers, are usually fully filled with magazine bundles, envelopes and parcels, and weigh up to 70 lbs. In general, at all distribution centers several factors contribute to the creation of awkward and uncomfortable handling situations for mail handlers:

- the heavy weight of the sacks and letter trays and letter tubs;
- the lack of handles, eyelets or any other helpful operator interface on the sacks and parcels;
- unpredictable shape, size, and weight of the sacks and letter trays and letter tubs in a work station.

During repetitive pick and place maneuvers, the above elements have increased the risk of wrist, finger, and back injuries among mail handlers.

To decrease the risk of injuries and to expedite mail processing, the US Postal Service (USPS) has employed Fanuc robotic devices to automate some of its mail handling systems. The Fanuc robots were not adaptive enough to handle the unpredictable nature of mail handling processes and therefore the USPS, at the time of the writing this article, is considering other robotic devices to automate mail-handling tasks in distribution centers. The state of technology in robotics is not at the point that it can automate USPS distribution centers without substantial modifications to both distribution centers and the infrastructure of mail processing. The most feasible and efficient solution to minimize the risk of injuries is to improve mail-handling stations by employment of assist devices, not to replace the mail handlers with robots. The following sections describe some of the mail handling stations that can easily be equipped with IADs.

4.3.1 Transfer of sacks from slide to carts or conveyor belt

The sacks come down a large slide and are manually loaded onto either the nearest conveyor belts or onto carts. The sacks are often very heavy and have no operator interface of any kind, which makes them difficult to grasp. This makes the process very slow and inefficient. IADs can easily be installed from above to load the sacks onto either the nearest conveyor belts or onto carts. There are very few limitations; the slide and conveyor belts are clear from above, and the carts used to receive sacks are open on
GM workers in several equal lifting operations using various conventional lift devices and the IAD. During the lifts, the body posture of the worker was recorded from a sagittal view using an active marker motion analysis system. The quantitative experiments resulted in a set of performance data for the IAD. The data showed that to move an object, the IAD has the lowest force-to-speed ratio than any other device (smallest impedance). In other words for a given operator force, the IAD has the highest speed or to move a load at a certain speed, the IAD requires the least amount of operator force. The subjective results are from the questionnaire that the test subjects (GM assembly workers) were requested to fill in after performing the test. Based on the response to the questionnaire, the IAD received the highest rank in terms of "comfort of use", "ease of control", "accuracy of control" and "compensation for load variation".

Fig. 4: Dr. Akella of GM during evaluation of IAD by installing a battery on a truck.

Fig. 5: Figure on the left shows a GM worker wearing reflective markers at his ankle, knee, hip, shoulder, elbow, and wrist during an experiment with a IAD. Figure on the right shows a computer model of the worker that is used to calculate the joint torques and LSS1 force using the force and position measurements.

4.3 Delivery services

Postal services across the world use sacks and trays to hold letters, magazines and small boxes. These sacks and trays, which are handled manually by mail handlers, are usually fully filled with magazine bundles, envelopes and parcels, and weigh up to 70 lbs. In general, at all distribution centers several factors contribute to the creation of awkward and uncomfortable handling situations for mail handlers:

- the heavy weight of the sacks and letter trays and letter tubs;
- the lack of handles, eyelets or any other helpful operator interface on the sacks and parcels;
- unpredictable shape, size, and weight of the sacks and letter trays and letter tubs in a work station.

During repetitive pick and place maneuvers, the above elements have increased the risk of wrist, finger, and back injuries among mail handlers.

To decrease the risk of injuries and to expedite mail processing, the US Postal Service (USPS) has employed Fanuc robotic devices to automate some of its mail handling systems. The Fanuc robots were not adaptive enough to handle the unpredictable nature of mail handling processes and therefore the USPS, at the time of the writing this article, is considering other robotic devices to automate mail-handling tasks in distribution centers. The state of technology in robotics is not at the point that it can automate USPS distribution centers without substantial modifications to both distribution centers and the infrastructure of mail processing. The most feasible and efficient solution to minimize the risk of injuries is to improve mail-handling stations by employment of assist devices, not to replace the mail handlers with robots. The following sections describe some of the mail handling stations that can easily be equipped with IADs.

4.3.1 Transfer of sacks from slide to carts or conveyor belt

The sacks come down a large slide and are manually loaded onto either the nearest conveyor belts or onto carts. The sacks are often very heavy and have no operator interface of any kind, which makes them difficult to grasp. This makes the process very slow and inefficient. IADs can easily be installed from above to load the sacks onto either the nearest conveyor belts or onto carts. There are very few limitations; the slide and conveyor belts are clear from above, and the carts used to receive sacks are open on
top. Moreover mail handlers can work without crossing paths, which allows for the possible set up of several IADs in parallel thus increasing throughput. At some distribution centers, a mix of sacks and boxes must be handled simultaneously. One must use either one end-effector capable of handling both sacks and boxes or two different types of end-effectors each suitable for either sacks or boxes. IADs will greatly enhance the efficiency of this workstation. At the very least IADs will make the job at these workstations less strenuous and safer for the mail handlers.

4.3.2 Sack Sorter

In this workstation, mail sacks come down a narrow chute, drop onto rollers, and are then manually moved directly onto rolling carts or OTRs (Over The Rails) based on destination. The majority of items coming down the chute are sacks, although other items such as boxes may come down as well. The sacks weight can vary from light (10-20 lbs.) to very heavy (70+ lbs.). Each sack sorter has 15–20 OTR’s (or other type of cart) arranged around the rollers in a sawtooth configuration. Due to the roller configuration, the sorting process is naturally divided between both sides of the sorter. Therefore, it would be possible to set up two parallel rails, with one rail on each side of the conveyor rollers. Each rail would hold an IAD so that two mail handlers could sort sacks simultaneously without interfering with each other.

4.3.3 Tray strapping station

This is a procedure where straps are fastened around letter trays and letter tubs that have lids on top to ensure that the tubs and trays stay closed. The mail handler must manually lift letter trays and letter tubs out of a cart and place them into a strapping machine. After strapping, mail handlers place the strapped trays and tubs into a cart or onto a conveyor belt. This workstation is suitable to be equipped with IADs because it consists of stationary machinery. There is no limitation in installing IADs on the ceiling since the strapping machine is clear from above, and the carts are open on top.

4.3.4 Bar Code Sorter (BCS)

After being sorted by a bar code reader, letter trays are placed into carts and passed to an unloading point. The open-topped letter trays weigh up to 25 lbs. each. This workstation requires a two-handed IAD or some other type of grabbing device that will not spill the letters. One could install one IAD on a U-shaped track or two IADs on two parallel tracks. There is no limitation in installing IADs on the ceiling since the machine is clear from above, and the carts are open on top.

4.3.5 Flat Sorting Machine (FSM)

Flat trays are passed through the FSM on conveyor rollers and manually loaded onto carts. In this station, only flat trays are processed, and as shown in Fig. 12, have two grip holes on opposite sides that serve as handles. Open-topped flat trays require two-handed or one-handed IADs with hooks only. No sacks are processed here. There are very few
top. Moreover mail handlers can work without crossing paths, which allows for the possible set up of several IADs in parallel thus increasing throughput. At some distribution centers, a mix of sacks and boxes must be handled simultaneously. One must use either one end-effector capable of handling both sacks and boxes or two different types of end-effectors each suitable for either sacks or boxes. IADs will greatly enhance the efficiency of this workstation. At the very least IADs will make the job at these workstations less strenuous and safer for the mail handlers.

4.3.2 Sack Sorter
In this workstation, mail sacks come down a narrow chute, drop onto rollers, and are then manually moved directly onto rolling carts or OTRs (Over The Rails) based on destination. The majority of items coming down the chute are sacks, although other items such as boxes may come down as well. The sacks weight can vary from light (10-20 lbs.) to very heavy (70+ lbs.). Each sack sorter has 15-20 OTR's (or other type of cart) arranged around the rollers in a sawtooth configuration. Due to the roller configuration, the sorting process is naturally divided between both sides of the sorter. Therefore, it would be possible to set up two parallel rails, with one rail on each side of the conveyor rollers. Each rail would hold an IAD so that two mail handlers could sort sacks simultaneously without interfering with each other.

4.3.3 Tray strapping station
This is a procedure where straps are fastened around letter trays and letter tubs that have lids on top to ensure that the tubs and trays stay closed. The mail handler must manually lift letter trays and letter tubs out of a cart and place them into a strapping machine. After strapping, mail handlers place the strapped trays and tubs into a cart or onto a conveyor belt. This workstation is suitable to be equipped with IADs because it consists of stationary machinery. There is no limitation in installing IADs on the ceiling since the strapping machine is clear from above, and the carts are open on top.

4.3.4 Bar Code Sorter (BCS)
After being sorted by a bar code reader, letter trays are placed into carts and passed to an unloading point. The open-topped letter trays weigh up to 25 lbs. each. This workstation requires a two-handed IAD or some other type of grabbing device that will not spill the letters. One could install one IAD on a U-shaped track or two IADs on two parallel tracks. There is no limitation in installing IADs on the ceiling since the machine is clear from above, and the carts are open on top.

4.3.5 Flat Sorting Machine (FSM)
Flat trays are passed through the FSM on conveyor rollers and manually loaded onto carts. In this station, only flat trays are processed, and as shown in Fig. 12, have two grip holes on opposite sides that serve as handles. Open-topped flat trays require two-handed or one-handed IADs with hooks only. No sacks are processed here. There are very few
limitations for installation of IADs; the FSM and conveyor rollers are clear from above, and the carts used to receive trays are open on top.

Fig. 12: FSM (Flat Sorting Machine)

Fig. 11: BCS (Bar Code Sorter)

5 References

8. Pneumatic human power amplifier module (U. S. Patent #5,915,673)
9. Human power amplifier for vertical maneuvers (U. S. Patent #5,865,426)
10. Human power amplifier for vertical maneuvers (U. S. Patent #6,299,139)

A Hybrid Control System for Effective Warehouse Order Fulfillment

Byung-In Kim, Sunderesh S. Heragu, and Robert J. Graves
Decision Sciences and Engineering Systems Department
Rensselaer Polytechnic Institute

Art St. Onge
St. Onge Company

Abstract

Customers will require better quality, faster delivery, and lower cost of goods and services in the future. In order to satisfy the customers’ requirements, enterprises need to have warehouse systems that are more flexible and adaptable to changing demands. To make a system more flexible and responsive as well as more efficient, its planning and execution phases must be integrated. In this paper, an intelligent agent based hybrid framework for integrating planning and execution is proposed and applied to an industrial warehouse order picking problem. It combines features of both hierarchical and heterarchical models. There are three levels of hierarchy in the framework: system level, control level, and execution level. The system level agent, with its global perspective, makes a balanced and synchronized order sequence and efficiently assigns resources to each order. A mathematical programming model and a genetic algorithm are developed for the higher level agent. The middle control level agent takes the resource assignment decision from the system level agent and guides the lower execution level agent to achieve the system objective. The execution level agents, consisting of order agents and resource agents, make decisions based on the real time conditions. They can change the predetermined resource assignments with permission from the control level agent. The effectiveness of the hybrid framework is demonstrated through detailed comparisons with other frameworks using real-world data.

1. Introduction

Through a workshop and a delphi survey, a committee on Visionary Manufacturing Challenges for 2020 projected that flexibility and responsiveness will be more critical for manufacturing in the future [18]. Customers will require better quality, faster delivery, and cheaper cost of goods and services. In order to satisfy the customers’ requirements,