Peter R. Wurman
Engineering Fellow, Kiva Systems, inc.
pwurman@kivasystems.com
225 Wildwood Ave
Woburn, MA 01801

Applications of Mobile Robots in Warehouses

When it comes to robotics, for decades our imaginations have far outstripped our capabilities. Practical applications have been surprisingly hard to come by, with stationary robots in manufacturing environments an area that has yielded the most success. Recently, US companies have gained traction in fields involving mobile robots. One such application is the inventory management system developed over the past four years by Kiva Systems for use in fulfillment and distribution centers.

Kiva's systems used hundreds of mobile robots to move small inventory shelves within the warehouse. Rather than having workers move to the inventory, Kiva's robots move the inventory to the worker, more than doubling the productivity of the warehouse employees. This innovation produces many side benefits, including greatly reduced cycle times, unparalleled flexibility, and an unprecedented of speed to deployment. Kiva's system is practical at this point in time because it uses mobile robots for what they are good at—moving reliably—and allows people to continue to do the things for which robots are not cost effective—seeing and manipulating a wide variety of inventory items, from resistors to lipstick to nested garbage cans.

The basic concept is straightforward. Inventory is stored in bins on storage "pods". These pods sit on bases about 18" off the ground. The robots can move under the pod and lift it from below, then carry the pod to any destination in the building. To fill an order for a customer, the material handling software determines where the inventory is stored, selects some pods to bring to the station, and then assigns the delivery tasks to some robots. When the robot delivers the pod, the operator is directed by the workstation to pick the correct quantity from the correct bin and place it in the customers box. By working on several orders at a time, the operator keeps a steady stream of inventory flowing to her station. When the operator is done picking inventory, the robot delivers the pod to some storage location.

Although these mobile inventory systems work, and have proven themselves dependable enough for companies like Staples and Walgreens to rely on them to fulfill significant portions of their daily demand, the application of mobile robots to this industry is still in its infancy. For the economic benefits of mobile inventory systems to transfer to a large number of US businesses, these we need to continue to drive the cost of the hardware down while increasing the power of the software systems that control the robots. The following research areas will have the greatest impact on the ability of US companies like Kiva to deploy mobile inventory systems in the US and around the world.

1) Lower-cost, more reliable sensors. This is perhaps the most traditional research area, but one in which progress benefits almost every company involved in robotics. Under this general heading we include obstacle detection and improved, indoor localization. None of the current localization technologies work well enough to provide the resolution needed for these mobile inventory systems. In these environments, dense with plastic and metal shelving units, robots need to be able to determine where they are to within an inch at all times.
2) Resource allocation in dynamic environments. This research topic is the most unique to this application area. Although there has been considerable research in the area of resource allocation in multi-agent systems, there have been precious few real applications that involve more than a few mobile robots, and the majority of those are military applications. A Kiva system represents a new and very real application area for researchers in multi-agent resource allocation. The basic challenge is to allocate hundreds of robots to thousands of pickup and delivery tasks. Because many of the warehouses are receiving orders all day long, these allocation decisions must be made in real time. Furthermore, the real-time, adaptive nature of the mobile inventory system makes it possible to experience classic dynamic control phenomenon like oscillations, congestion, and instabilities. Among the challenges are:
    a. Task allocation – choosing which inventory pod to assign to a worker and which robot will make the delivery.
    b. Scheduling – arranging the deliveries at a station so that the workers queue of work neither overflows nor runs dry.
    c. Slotting – automatically choosing which inventory locations to use for storing inventory. Decisions made during inventory replenishment affect the delivery patterns when the orders are being filled.
    d. Storage arrangement – determining where to store the inventory pods based on the expected popularity of the products on it.
    e. Elevator load balancing – when bottleneck resources are part of the system, like specialized elevators (lifts) between mezzanine decks, the allocation schemes must make extremely effective use of the lifts.

    To facilitate research in this area, we have created a publically available simulation called Alphabet Soup (http://research.csc.ncsu.edu/alphabetsoup/). Alphabet Soup is an abstraction of a Kiva system in which "bucketbots" can move buckets of letter tiles from replenishment stations to word building stations. "Orders" in the simulation are created simply by feeding in a dictionary file. The simulation is designed to make it easy for researchers to study resource allocation topics like those listed above. Alphabet Soup was recently used by faculty at Georgie Tech's Supply Chain and Logistics Institute to support a class project.

While companies like Kiva remain focused on the short term, there are many avenues for longer term research to impact the applications of these technologies in industry.