# Industrial Mobile Manipulation

Mobile industrial robot development began decades ago with the first Automated Guided Vehicles (AGVs). Early AGVs were unintelligent vehicles employed to move loads in factories following paths that were marked with wires buried in the factory floor. These vehicles were only practical for permanent installations in unchanging environments; “reprogramming” a first generation AGV required that the path be removed from the floor and reinstalled. [CITE I-FORK]

More modern AGVs have eschewed physically-marked paths in favor of virtually-defined paths. The AGV uses sensor systems to localize itself in the factory and navigation software to follow paths, which can be statically defined or dynamically chosen by a higher-level planner. The higher level planner chooses paths for an AGV from amongst a graph of paths through the factory or warehouse. A single high-level planner may coordinate multiple AGVs to prevent traffic jams and allocate tasks. [CITE VIVALDINI] Although these modern AGV systems are more flexible than their predecessors, they still depend on an ordered factory or warehouse environment, and are not designed to cooperate with human workers. They execute pre-programmed routines to move loads between loading docks. Implementing such a system requires that all of the possible paths for the AGVs be predefined, which makes commissioning such a system a lengthy and labor-intensive process. Predefining all of the paths for an AGV may not be practical if the inventory system is large and does not have readily-defined nodes such as loading docks. These systems are useful for tasks such as pallet transportation, and many such systems are fork lifts [CITE Garibotto]. However, AGVs are inflexible; they cannot adapt to changing inventory organization, changing assembly line configurations, or changes in their environment. An obstacle placed along an AGV path could disable an entire AGV system by creating a bottleneck or blockage.

At least one company, Kiva Systems, has moved from the AGV paradigm to a smart-warehouse system[CITE KIVA AGV]. In this type of system, all of the inventory is stored on pallet-like mobile shelves, and a group of mobile drive units rearrange and deliver the shelves as necessary to bring items to assembly and packing stations. Kiva robots cannot manipulate individual items, so the task of loading and unloading the shelves is left to human pickers, and the robots are used purely as mobile bases for the shelves. This system is an evolution from the traditional AGV in that there are no pre-planned paths; instead, the mobile robots are entirely free to move through the warehouse environment. This system also has some advantages over AGV systems that stem from the entire inventory being movable. Namely, the warehouse is constantly being reorganized as it is used. This allows the inventory management system to optimize the inventory, moving items around to make commonly-needed items more accessible and improve the speed of the overall system. [cite KIVA] Although the Kiva system does not require that paths be prelaid or preplanned, it does require that a warehouse be specifically designed for and used exclusively by its robots. The system cannot be used with existing inventory shelves, only with the movable shelves designed for its robots. It also requires that the inventory environment be outfitted with a grid of barcodes on the floor to facilitate localization.

Mobile manipulators have made little headway into industry, partly because of the rarity and cost of mobile manipulators. [cite youBOT] However, researchers have been exploring the application of mobile manipulators in industrial settings for several years. In 2004, a group at the University of Verona, Italy devised a mobile manipulator for the pharmaceutical industry. [CITE COSMA] This robot consisted of a custom-made 5 DOF manipulator with one passive DOF mounted on top of a commercially-available mobile base. The system used a vacuum gripper to pick up cardboard boxes from pallets and put them on shelves. This system was capable of navigating freely through a partially structured dynamic environment using a local and global planner. The resulting robot is functionally similar to ABBY, but was to be used for the task of loading items from pallets into an inventory shelving system, whereas ABBY’s purpose is to pick from inventory and deliver items to assembly stations. More recently, in 2011 a group at the Intelligent Systems and Production Engineering Research Center for Information Technology in Karlsruhe, Germany developed a bimanual manipulator using a custom drive base and two KUKA Lightweight Robot arms.[CITE HERMANN] It used a Microsoft Kinect, two high resolution cameras, and three LIDAR scanners for perception as well as force feedback in its manipulators. This platform was exceptionally capable, but was designed more as a general-purpose mobile manipulator than as an industrial robot. This platform’s price was not listed, but affordability was not a goal of the project. The main focus of the research was on the development of a software platform for mobile manipulation and on developing new planning methods for the robot’s manipulators.