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MagneMotion's linear synchronous motor (LSM) driven assembly automation and material handling system designs

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Abstract

Purpose – This paper aims to introduce novel linear synchronous motor (LSM) driven assembly automation and material handling system designs with examples.

Design/methodology/approach – Discusses novel LSM technology principles with some practical system design and configuration examples for automated assembly and material handling. The high energy density and rugged design offers high duty cycle, high power, rapid acceleration, improved speed, high positioning repeatability, and increased performance for demanding installations.

Findings – LSMs can increase throughput, reliability and payload information feedback. They can also decrease maintenance requirements, and the total cost of installation. MagneMotion's patented QuickStick system propels and controls each vehicle independently by interacting with a permanent magnet array mounted to each vehicle. As a consequence, the vehicles do not require communication or power cables, allowing a broad range of flexible, reconfigurable configurations and move profiles.

Practical implications – LSMs can increase throughput, reliability and payload information feedback. They can also decrease maintenance requirements, and the total cost of installation.

Originality/value – Discusses novel LSM technology principles with some practical system design and configuration examples for automated assembly and material handling.

Keywords Linear programming, Assembly, Automation, Lean production

Paper type Technical paper

Introduction

In comparison to current conveyor and material handling system designs, linear synchronous motor (LSM) driven assembly automation technology offers fast, accurate and cost effective solutions.

As an example, MagneMotion's patented position sensing and control techniques allow for precise control of position, as well as acceleration and deceleration to permit the safe transport of sensitive or fragile loads. Within this scaleable-size, feedback controlled system, single or multiple vehicles (i.e. moving elements, or modules) simultaneously operated in different directions on the same track can also be indexed and positioned with great accuracy. The lack of moving parts and wearing elements in these motors (there are no brush or sliding contacts on the vehicles) greatly increases their reliability and makes them attractive for use in demanding automated assembly, material handling, pharmaceutical packaging, clean room applications, and even in hazardous environments.

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Principles of operation, system architecture and building blocks

LSM is a modular, linear synchronous motor solution for assembly automation and material handling. The core technology is the linear electric motor. This is an electro-mechanical system that can convert electrical energy directly into linear motion without using any rotary components. LSMs represent a special type of the family of linear motors.

Consider, that inside a conventional rotary synchronous motor the outer ring, or the stator is stationary, and the inner ring, the rotor can rotate about the shaft using the energy of a generated electro-magnetic field (Kim *et al.*, 2006). One can imagine an LSM as a sliced-up rotary electrical motor that is laid flat at each element, with the rotor being on the top. This system design, with additional stator elements can be expanded into theoretically infinite long linear modules. The key here is that in a LSM the moving element is attacked by the same electro-magnetic forces as in a rotary electric motor, but its motion becomes linear versus rotary.

LSMs are not far more efficient than rotary synchronous motors. Rotary motors are better able to control their gap and always have the rotor in proximity to the stator, so they can be

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more efficient. The real advantage of the linear motor is that it produces force in the desired linear dimension without needing a mechanical means to transfer it to that dimension.

Control system architecture and design examples

As shown in a conceptual diagram (Figure 1), in MagneMotion's QuickStick™ LSM, each vehicle has a magnet array attached to its underside. The magnet array is the motor secondary. The QuickStick™ LSM module contains the motor primary, as well as the driver/amplifier, position sensors, digital controller and serial communications (using an RS422 serial interface). There is typically a physical gap of approximately 3 mm between the primary and secondary, which is maintained by the vehicle wheels, or a set of rollers if the vehicle is a pallet (see actual design examples in Figures 2 and 3).

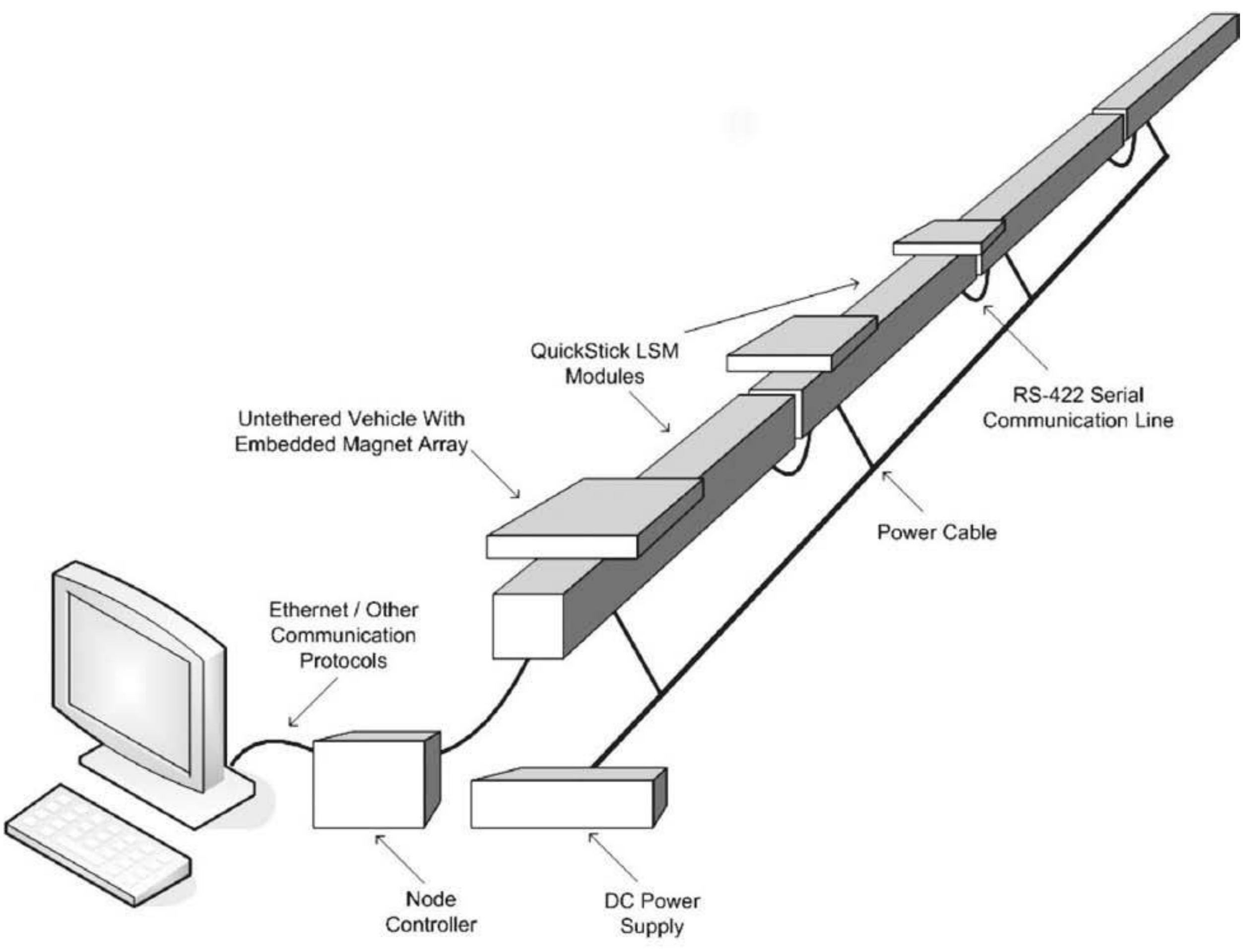
Each LSM module is divided into one or more motor blocks, or zones, and only one vehicle is allowed in a zone at a time. At the start of each session, each vehicle on the track is assigned an ID (identifier) and the system thereafter knows where each vehicle is at all times.

Each vehicle can also execute any number of sequential move profiles, that is typically generated by a higher level control system, and the profile is based on assembly sequencing, production schedules and other real-time evaluated data inputs. Permission is granted for a zone, or block far enough ahead so that the vehicle can stop before entering a block for which it does not have permission to enter. There is a limit on braking rate that determines when a vehicle needs to begin to stop.

When an LSM senses when a magnet array is above the motor block (or zone), it knows the vehicle ID, and what its current move profile should be. The windings are then excited based on that move profile and interact with the magnet array to create an electro-magnetic field. The vehicle then "rides" the electro-magnetic field over that motor block much like a surfer rides a wave, and readies itself to enter into the next zone.

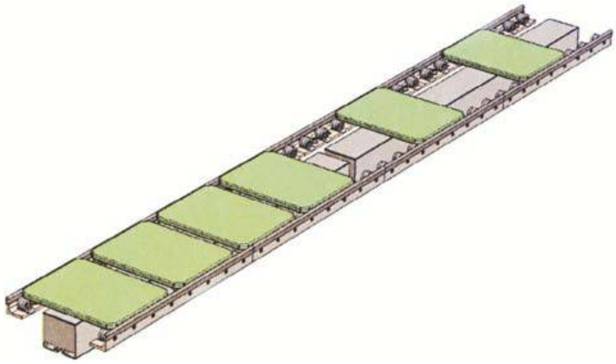
The RS422 communication daisy chain between QuickSticks allows permissions to be acquired for a vehicle as far ahead as is necessary for the specified acceleration and velocity limits. This process is entirely computer controlled, and, therefore, is very fast. Permissions are requested and granted in milliseconds, leading to smooth, constant velocity movement on an unobstructed path. QuickSticks regulate the velocity and acceleration of the vehicle based on the limits specified in the vehicle movement order.

Figure 1 The QuickStick LSM is a 1 m long linear motor module with embedded position sensors and control software



Source: Design courtesy of MagneMotion Inc., Acton, Massachusetts, USA

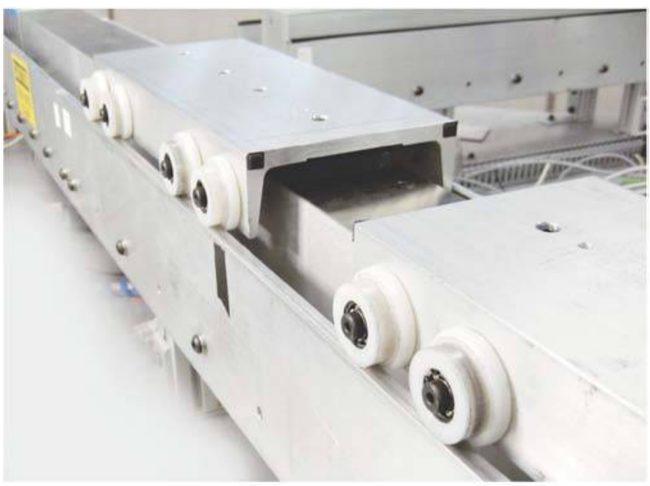
Figure 2 In this design example, multiple vehicles, or pallets, overlay two QuickStick modules connected end-to-end within a guide-way



Notes: The vehicles can travel simultaneously in both directions, following different move profiles, and do not require communication or power cables, allowing a broad range of flexible, reconfigurable configurations and system control strategies

Source: Design courtesy of MagneMotion Inc., Acton, Massachusetts, USA

Figure 3 A close-up view of the vehicles/carriers



Source: Design courtesy of MagneMotion Inc., Acton, Massachusetts, USA

QuickSticks along a single path are able to communicate directly with one another. Node controllers act as communication switches at junctions where more than two paths meet, such as at switches or turntables.

Design examples using linear synchronous motors

LSM combines pallet/vehicle propulsion, positioning and feedback in a single module. It can replace conveyor belts, hydraulic actuators, conventional electric (rotary) motors driving wheels, and propel magnetically levitated vehicles without physical contact. In comparison to other linear motion technologies, LSMs offer several benefits, including the following:

- *Increased reliability*. This is achieved by reducing the number of moving, and, therefore, wearing parts. Furthermore, in LSM systems, acceleration and braking are not dependent on friction but on the strength of magnetic flux, controlled by a feedback control system within the QuickStick (see the architecture in Figure 1 again).
- Improved performance via fast acceleration, accurate positioning and accurate vehicle movement control. (In various engineering design configurations speeds from 0 to 166 m/s (360 mph), forces from 0 to 3.1 MN can be achieved)
- Increased efficiency since vehicles have dual-direction of movement capability. This means that in an assembly cell, or line, the system's process sequence time, or takt time is not set by the fixed speed of the conveyor, since the vehicles can individually move up and down the track, following their own move profiles, under computer control. (Note that, collision is avoided by real-time zoning the track.)
- Provide more precise position control.
- Negotiate steep grades without depending on friction. (This means, that any slope is possible, including vertical.)
- Eliminate the need to have propulsion power and control on the vehicle.
- Vehicle can be passive.
- Ability to control multiple vehicles on complex trajectories.
- No need to transfer control signals to a moving vehicle (because the control signals travel in the static base of the system, i.e. inside the QuickStick LSM modules).

To illustrate some of the above listed design concepts, in Figure 4, we show a simple automated assembly layout under construction.

It is important to note, that the node controller (Figures 4 and 5) in this demonstration system performs several tasks, including the following:

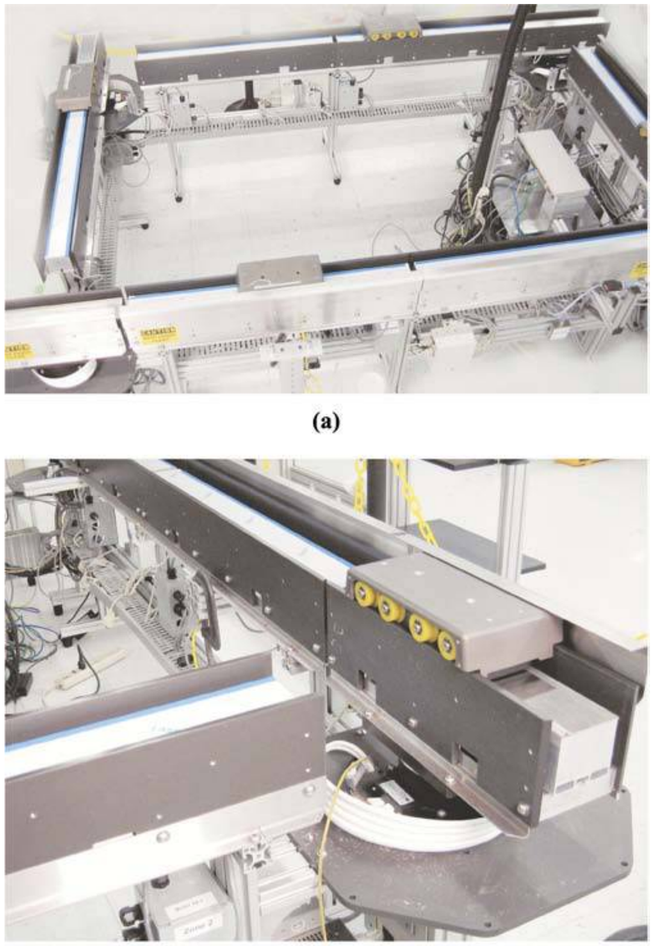
- Moves the turntables when required (to turn a vehicle to a different exit path or return a turntable so that a vehicle can enter through an entry path).
- Blocks communication between a QuickStick on the turntable and one off the turntable unless the QuickStick on the turntable is lined up with the on off. This prevents vehicles from getting permission to move on or off the turntable until it is in the correct position.
- Sends movement command to a QuickStick controlling a vehicle when received from the customer (host) system.

As can be seen, the heart of the control system is the networked node controller. It controls switches and turntables, it routes QuickStick messaging and vehicles to the appropriate path through a node. It forwards vehicle status and error status to the high level controller (HLC). It is an application that runs on one of the node controllers, and basically just provides a single interface to the system.

A track layout can be made up of several node controllers, but the customer system only needs to talk to one of them (the one designated the HLC), and it routes information to and from the other node controllers. As control topologies can become complicated, shown in Figure 6, the node controller, shown in Figure 7, is a crucial component of the system.

In this automated assembly system (under construction) one of the challenges was to let the vehicles cross the track in the

Figure 4 In this automated assembly system (under construction), one of the challenges were to turn the vehicles at 90° at the end of each track module



(a)

(b)

Notes: As illustrated in Figure 4a the solution was to build a Quick Stick module into the turning segments of the path too. The turntable motors are direct drive, meaning no gearbox is required. The only moving parts are the bearings, therefore they should be reliable as well

Source: Design courtesy of MagneMotion Inc., Acton, Massachusetts, USA

middle without risking any collision. Furthermore, in this system, different vehicles follow different positioning/movement strategies. As illustrated, the solution was to build a QuickStick module into the crossing segment of the path.

A turntable with an on-board QuickStick is used as a switch in the system shown in Figure 8. It allows a vehicle to traverse from any input path to any output path. The QuickStick on the turntable is only allowed to communicate with paths that it is lined up with. Any vehicle trying to get permission to go through the turntable when it is not lined up will not receive permission to enter the turntable, and due to the protection scheme, will come to a stop at the entrance of the turntable until permission is granted.

Summary

LSMs can increase throughput, reliability and payload information feedback. They can also decrease maintenance requirements, and the total cost of installation. The high-energy density and rugged design offers high-duty cycle, high-power, rapid acceleration, improved speed, high-positioning repeatability, and increased performance for demanding installations. The QuickStick LSM 1 m long linear motor modules have embedded position sensors and control software. Its built-in feedback controls, linked to a network, can regulate speed, acceleration and deceleration, direction of movement, vehicle traffic, and vehicle positioning. In this system, node

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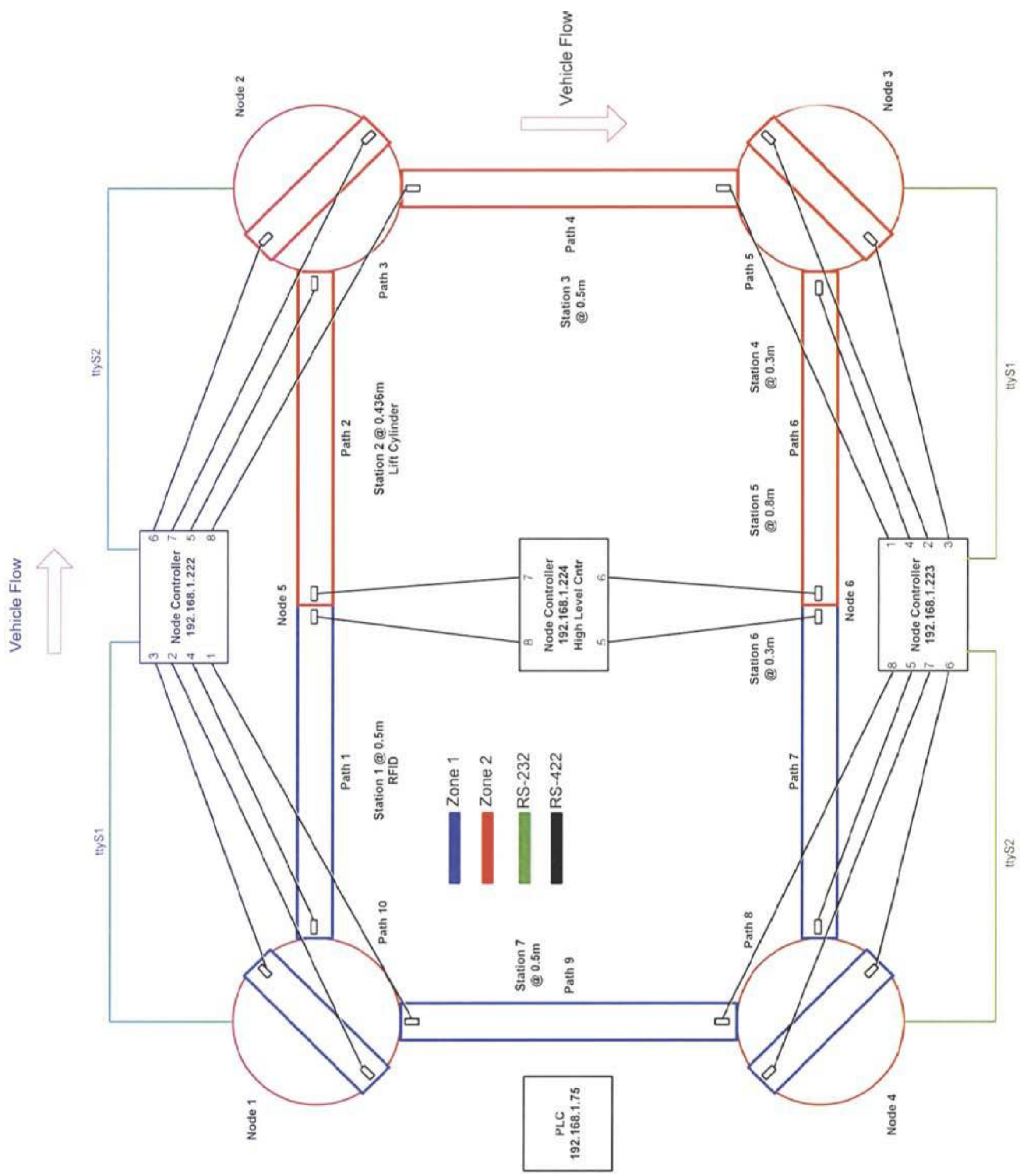
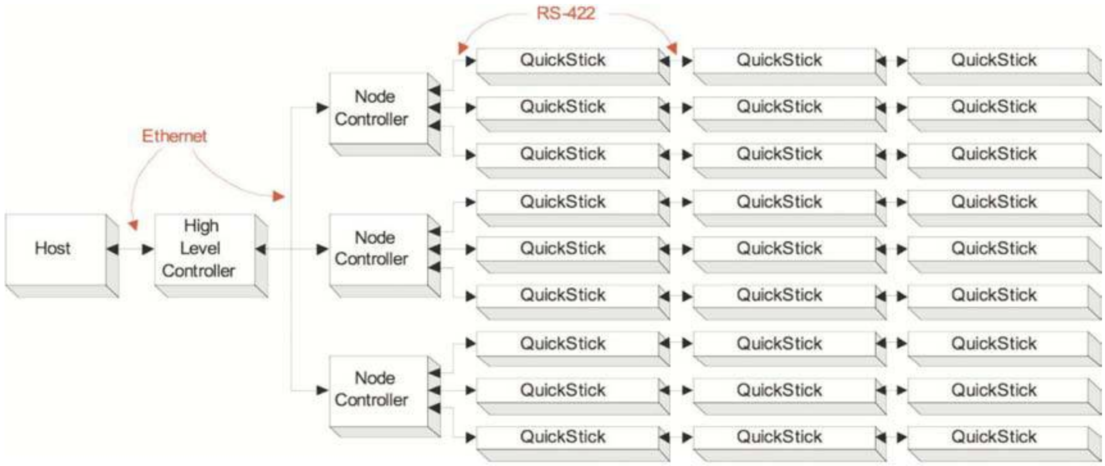
Figure 5 Node control networking diagram for the automated assembly track shown in Figures 4 (a)-(d)



Source: Design courtesy of MagneMotion Inc., Acton, Massachusetts, USA

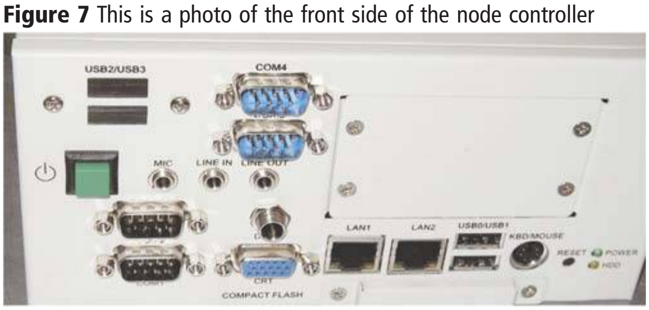
Figure 6 Each node controller can actually handle up to 320 QuickSticks on eight paths



Notes: In this diagram it is clear that the customer (host) system need only communicate with the 'High Level Controller' that runs on one of the Node Controllers

Source: Design courtesy of Magne Motion Inc., Acton, Massachusetts, USA

Figure 7 This is a photo of the front side of the node controller



Notes: Notable on the front are the Ethernet connections, as well as ports available for controlling turntables. On the back side (not shown) are the 8RS422 ports used to communicate with up to 8 paths of QuickSticks

Source: Design courtesy of MagneMotion Inc., Acton, Massachusetts, USA

Figure 8

Notes: In this automated assembly system (under construction) one of the challenges were to let the vehicles cross the track in the middle without risking any collision

controllers provide switching and routing capability and provide a customer interface to the system.

In summary, LSMs are very versatile. There are many application possibilities in automated assembly, material handling, packaging, and other areas.

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