The CIP Motion Peer Connection for Real-Time Machine to Machine Control

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Abstract

This white paper discusses how the Peer Connection enables a highly distributed and modular motion control architecture. This Peer Connection is un-intrusive in the system and easily layered across multi-vendor implementations - creating a unique, unifying real-time solution for electronic line shafting and camming applications for real-time machine to machine coordination. Today, no such solution exists in industry at this level of the network topology. The Peer Connection also allows motion planner execution to move from the controller to the drive, providing a major boost in overall system performance. Finally, the distribution of motion functions in the form of I/O devices, feedback sensors, and standalone converters (functionality that is already defined in today's Motion Device Axis Object,) results in a clean, efficient and modular control architecture that is easily deployed and easily scaled.

Keywords

Peer Connection, Distributed Motion, Modular Motion, Scaled Architecture, Performance, Machine to Machine Control

Introduction

The ODVA Distributed Motion SIG is currently defining a Peer to Peer CIP Motion connection that will allow for the easy distribution of real-time motion control information among multiple controllers and multiple device types. This capability, available to a multi-vendor industry, will allow CIP to become the leading technology in the industrial marketplace for peer to peer motion control for electronic line-shafting and camming applications.

The CIP Motion Architecture has some unique advantages in the market, over and above the competitive technologies that are currently available. Built on the CIP protocol, the CIP Motion technology can coexist and cohabitate with other Ethernet protocols and solutions in a harmonized and non-disruptive manner.

Revisiting some of its previous value statements, CIP Motion takes advantage of the fact that it is built on a common, standard, Ethernet stack. (See Figure 1.) This means that in addition to the Physical and Data Link layers defined in the IEEE-802.3 specification, the Common Industrial Protocol also utilizes the standard Network and Transport layers typically deployed in general Ethernet applications. This allows for all devices in a given system to easily interconnect, using standard switches, routers, and other standard infrastructure components.

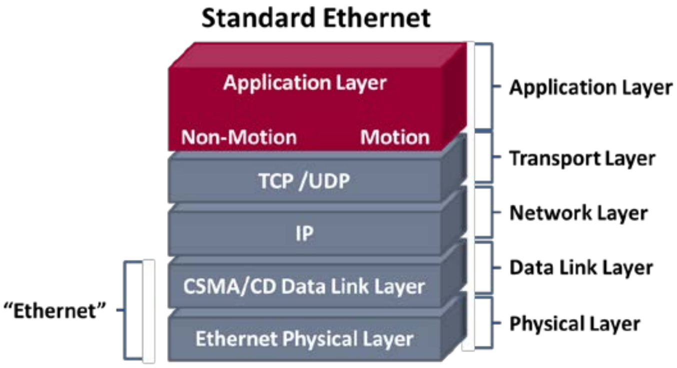

Figure 1

One benefit of this single network solution is that there is no need for a dedicated motion network. Topologically speaking, motion control can be placed anywhere in the infrastructure without the concern of physically isolating the traffic from other forms of traffic on the wire. Also, by utilizing existing Ethernet infrastructure, motion control can be easily layered into brownfield installations where hardware already exists. This facilitates expansion to installed systems and allows full advantage of well-established and robust management and diagnostic tools.

So what additional benefit does the CIP Motion Peer Connection bring to the motion architecture? Consider that the distribution of motion control across multiple cells or machine sections occurs at the level in the architecture where the line control functionality is accomplished. (See Figure 2.) At this level, there is typically integration of machine level HMI, recipe handling, historian data gathering, and engineering workstation functionality. The existing Ethernet wire that is being used for these disciplines can now be harnessed for sharing of real-time motion control information for machine to machine coordination! The Peer Connection is a very simple, homogenous and non-intrusive mechanism; it is easily layered across multi-vendor implementations, creating a unique and unifying real-time solution for electronic line shafting and camming applications.

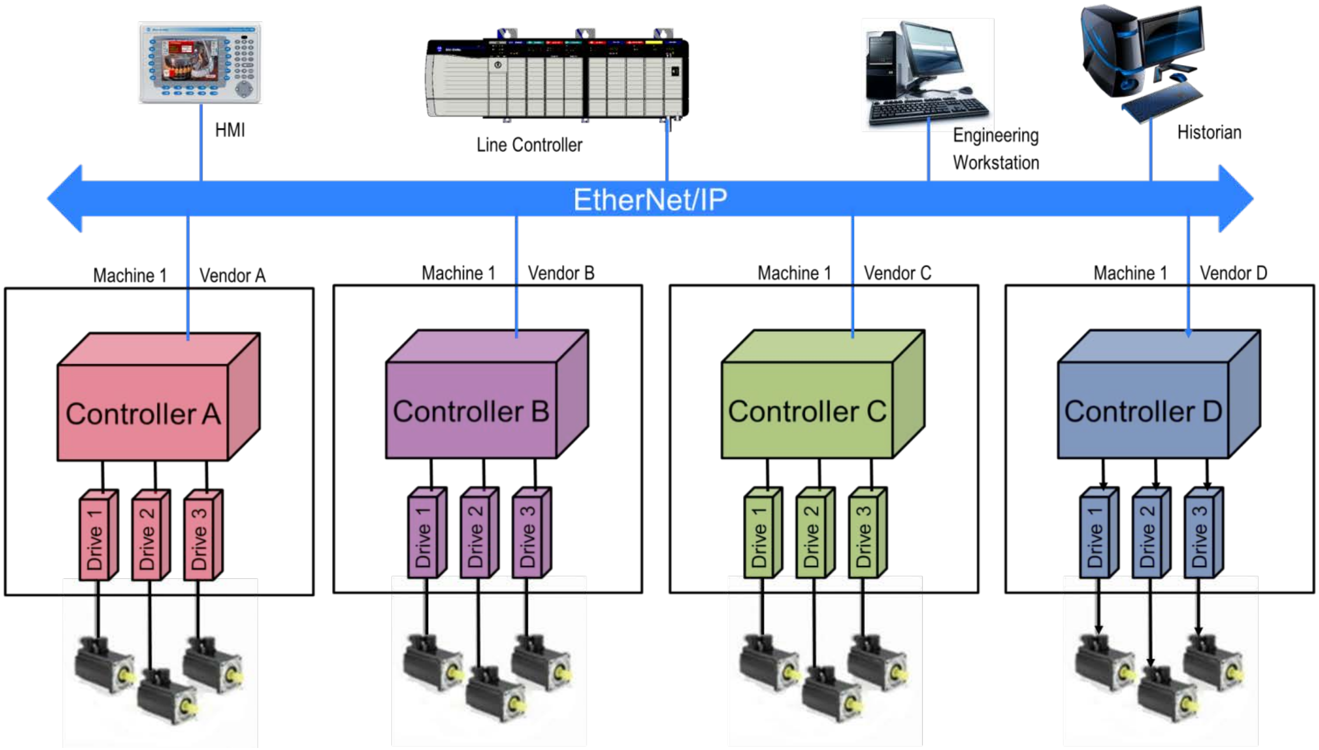

Figure 2

The Peer Connection Definition

At its core, the CIP Motion Peer connection definition follows the same principles embodied in the existing specification for the CIP Motion I/O connection. The CIP Motion Peer connection is designed to transmit high speed motion data from a producing controller or device to multiple consuming controllers or devices over a single multicast connection. (See Figure 3.) For example, time stamped master axis position data distributed by the CIP Motion Peer Connection allows consuming CIP Motion drives to precisely coordinate motion of their motors to the produced master axis position according to programmed electronic gearing or camming relationships.

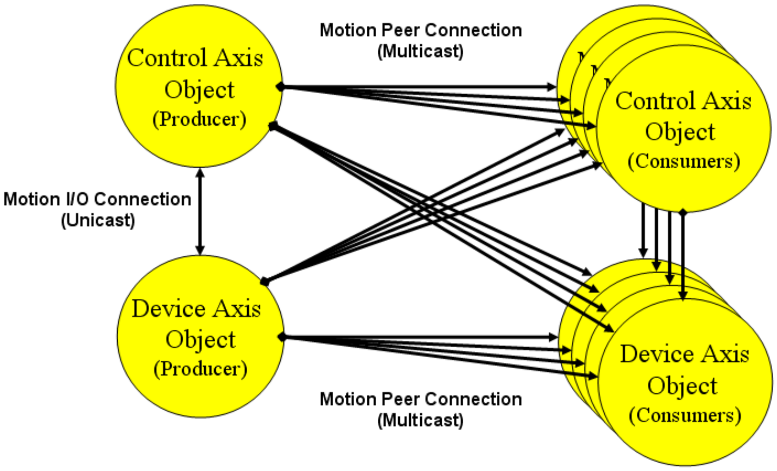
Control Axis Object (Producer)
Motion Peer Connection (Multicast)
Control Axis Object (Consumers)
Motion I/O Connection (Unicast)
Device Axis Object (Producer)
Motion Peer Connection (Multicast)
Device Axis Object (Consumers)

Figure 3

CIP Motion Peer Connection Use Cases

The CIP Motion Peer Connection has many use cases. As discussed previously, one application is to communicate produced axis information for distributed camming and gearing purposes. In this scenario, the position of a motor that is being driven in a machine cell by Vendor A may be produced as a master axis reference and sent out on the CIP Motion Peer Connection to be consumed by the other vendor controllers so that their respective axes can follow Vendor A's positioning information in a coordinated and synchronized manner. (See Figure 4 below.)

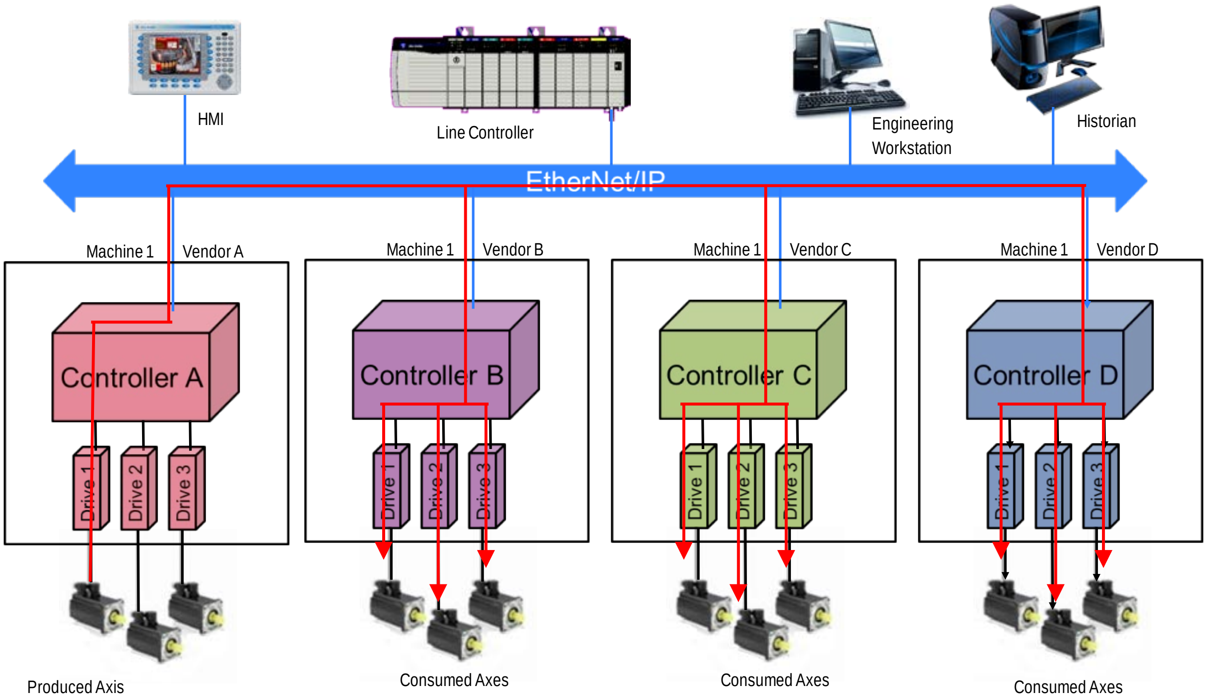

Figure 4

A second application is when the line controller itself generates a virtual axis in order to achieve full line synchronization and coordination. In this case, all the coordinated axes receive a common reference via the CIP Motion Peer Connection from the line controller in order to maintain coordination and proper phasing from axis to axis. This not only allows for coordinated camming and gearing functionality, but also allows for complete line starting and stopping as all sections are brought up to speed and brought down in speed in a synchronized manner. (See figure 5 below.)

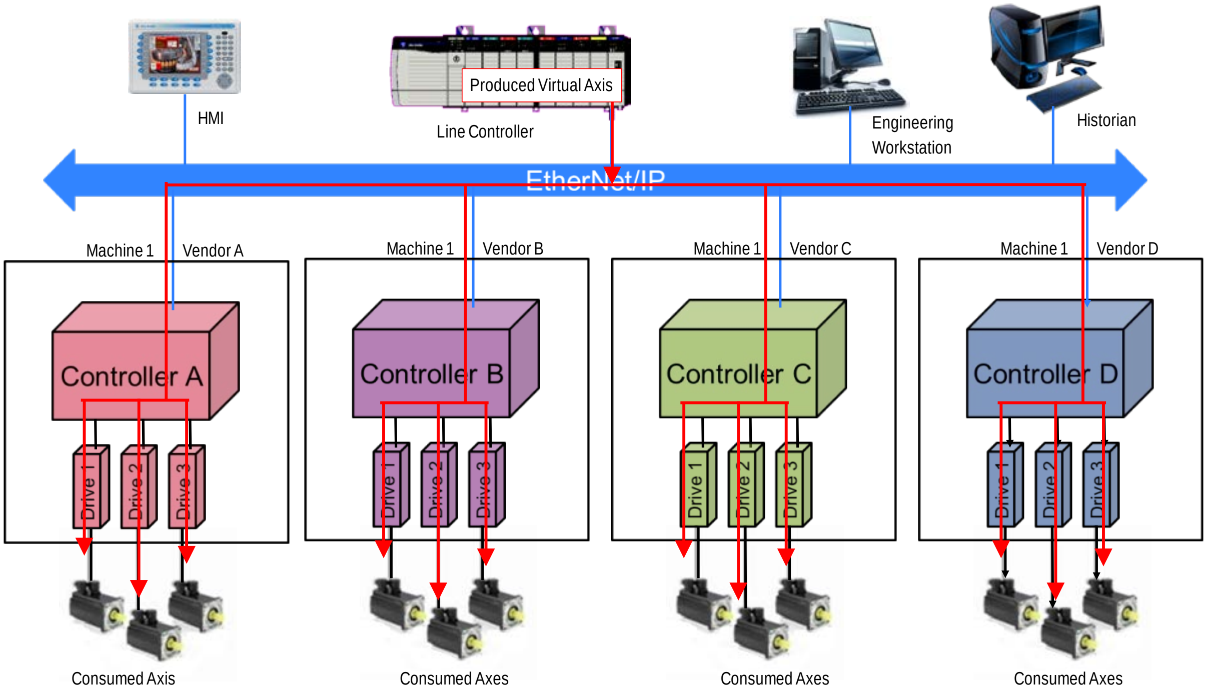

Figure 5

A third application for the CIP Motion Peer connection would be in the sharing of axis information for the coordination of robotics control. (See Figure 6.) In this case, a master reference could be produced over the CIP Motion Peer connection to allow for proper coordination of the robot as the entire line increases and decreases in speed. For example, the robot may be managing a “pick and place” application from one conveyor to another and needs to stay fully synchronized as the entire line is accelerated or decelerated.

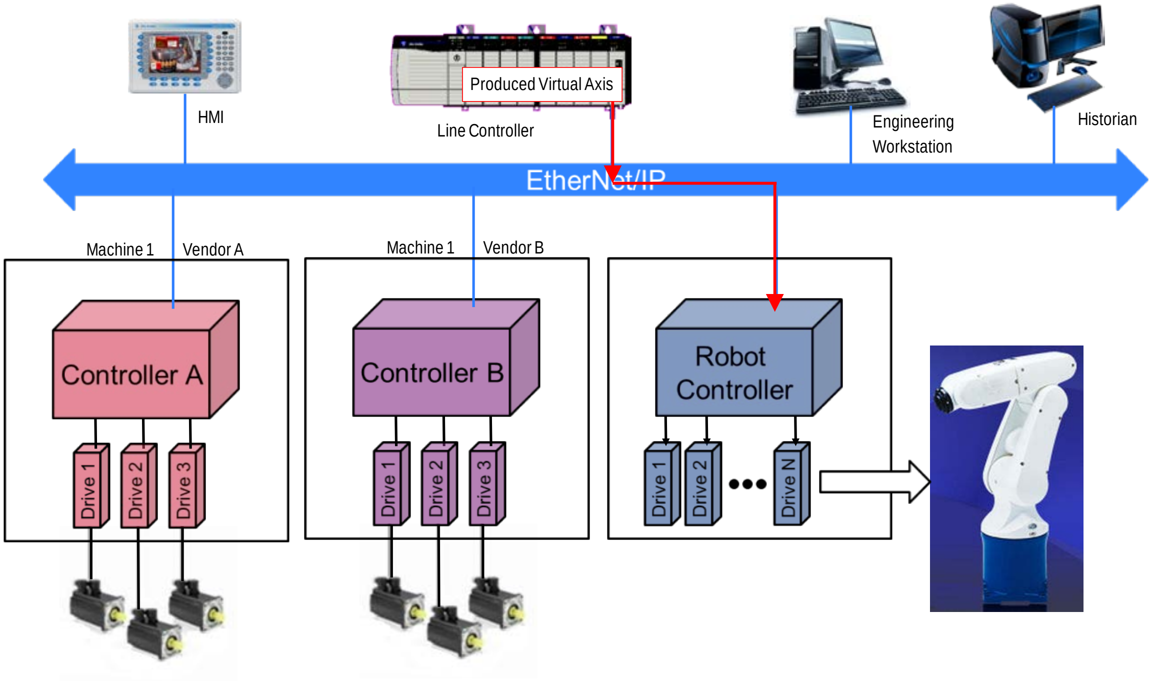

Figure 6

Distributed Performance via the Peer Connection

As shown above, the CIP Motion Peer Connection is designed to support controller to controller coordination – but it is also designed for controller to device, and for device to device motion coordination. This allows the CIP Motion devices to execute motion functions typically performed by the controller or by full featured servo drives. In short, the advent of the CIP Motion Peer connection represents a major step toward a Distributed Motion Control architecture, signaling a significant paradigm shift in the industry.

There are many benefits to moving toward a distributed motion architecture. One of the inherent benefits is its impact on overall system performance. To date, the Motion Planner has been executed exclusively by a controller as part of the controller's Motion Task. In this arrangement, the controller's Motion Planner is producing motion reference information to multiple drives in the system. (See Figure 7.) As a result, the Motion Planner Update Period for this controller needs to be configured to meet the requirements of the fastest axes on the machine- dictating the Motion Task Update Period for all the axes on the machine. Since most axes do not need to run at the same, fast rate, processing capability is wasted in this "one-to-many" model.

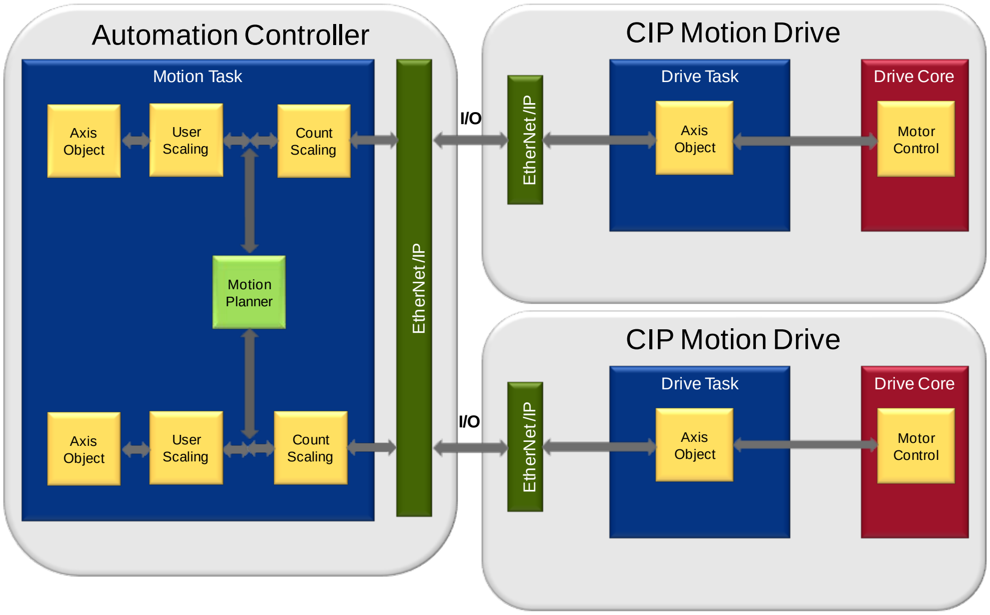

Figure 7

By moving the Motion Planner function to the CIP Motion devices, the Motion Planner Update Period of these high performance axes no longer dictates the Motion Task Update Period in the controller. The reduction in Motion Task update rate translates directly to a reduction in the CIP motion connection update rate, resulting in reduced network loading. Furthermore, with the distribution of the computationally intensive Motion Planner function to the end devices, Motion Task execution time in the controller is also significantly reduced. (See Figure 8.) The combined impact of reduced connection update rates and Motion Task execution time translates to a dramatic increase in motion control system capacity and performance.

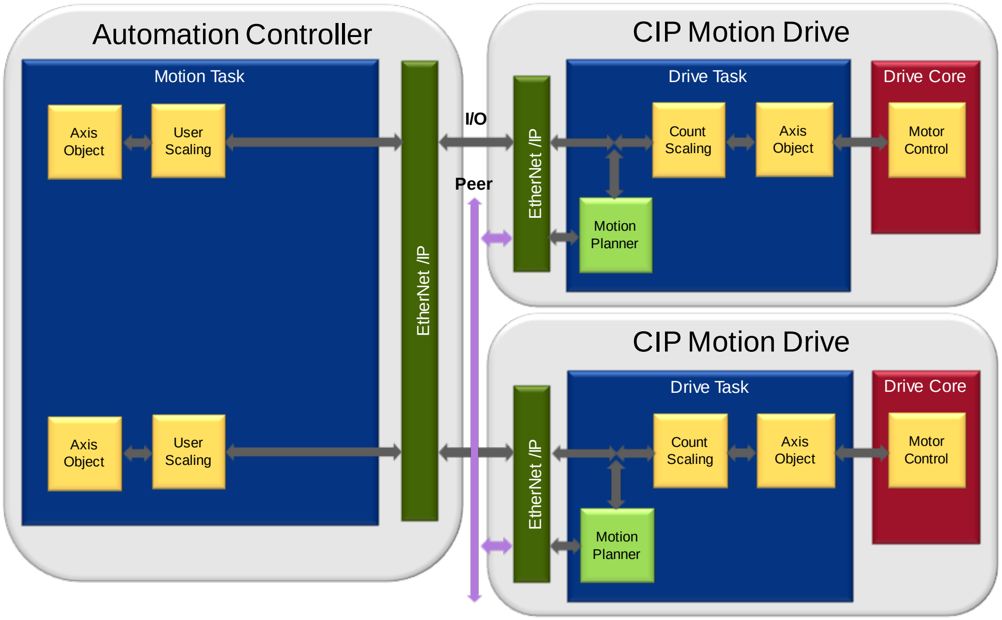

Figure 8

In addition to increased motion control system capacity, motion control dynamic performance has a strong dependency on the Motion Planner Update Period. This determines how frequently the Motion Planner function updates the command position applied by the drive. The faster the command position update rate, the more points are placed on the motion profile, which reduces the interpolation error in following the commanded path. The attraction of running the Motion Planner in the drive is that, since there is typically only 1 planner instance per drive, the planner can be run at a very fast update rate (i.e. 1 msec or less) resulting in outstanding dynamic control. In addition, if the planner were to run at the same rate as the servo update rate, the need to interpolate data between the planner and the position loop would disappear – reducing command position update delay and facilitating a simpler design.

To appreciate the impact of the Distributed Motion Control feature, consider a CIP Motion control system running a high performance packaging machine producing 1000 products per minute using a 1 millisecond Motion Task Update Period. In this application, one product is being processed every 60 msecs. If there were 30 axes of control required for this machine, a controller based planner would need to calculate all 30 axes every 1 msec, representing a sizeable load on the controller's processing and communications capabilities.

However, if the planner functionality is moved to the device instead, then each drive can execute its own path planning functionality while the Peer Connection manages the information required for drive to drive coordination. In this architecture, the drive based planners can be run at a sub-millisecond update rate and the controller to drive cycle time period can be increased to 10 msecs or more without impacting the motion quality. As a result, the estimated system capacity can easily increase by an order of magnitude by distributing the planner function to the drive.

Distributed Motion Functionality

With CIP Motion, the Distributed Motion Control architecture is more than just distributing the controller's Motion Planner function to CIP Motion drives. Other motion functions may be distributed as well, creating new types of CIP Motion devices as illustrated in the following system diagram. (Figure 9.)

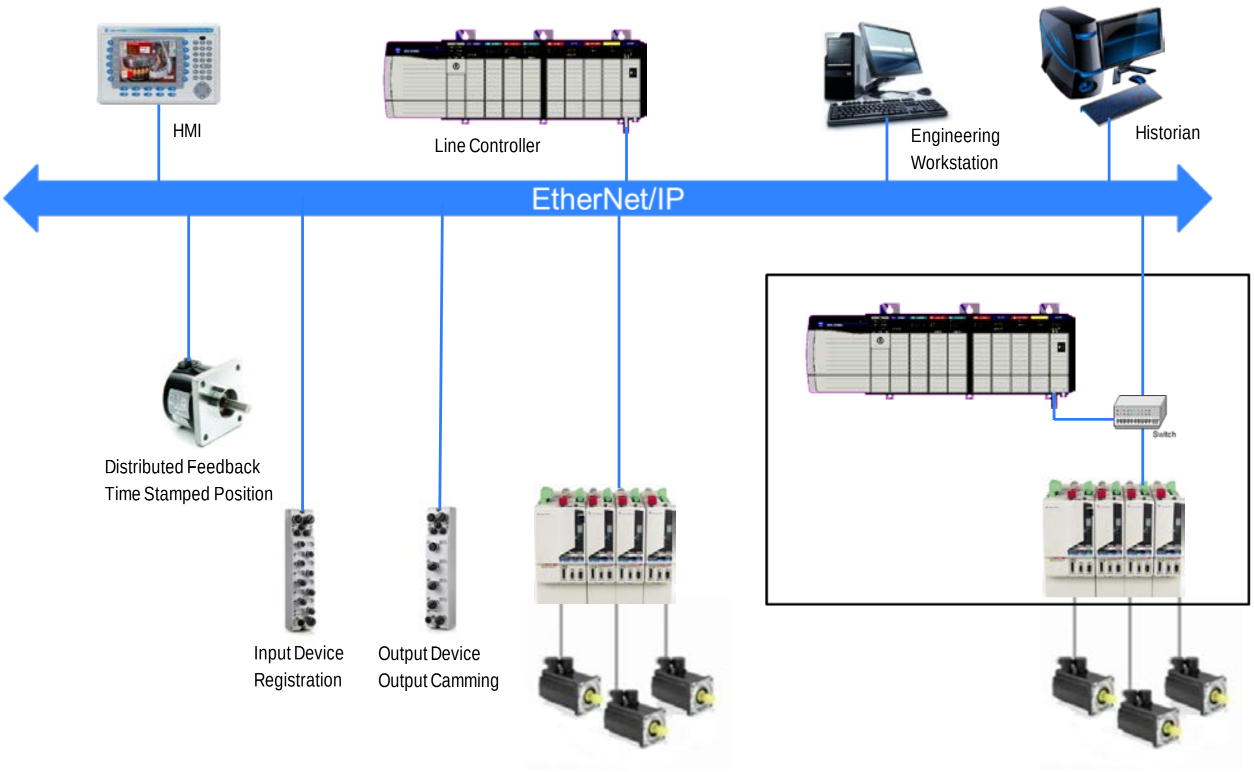

Figure 9

The ability to distribute motion functions across CIP Motion devices and controllers addresses a recent trend in lean drive design where drive vendors are off-loading certain functions of the traditional full featured servo drive to other devices. The following object diagram shows some of the functional components that might be separated out from the current CIP Motion Drive Axis Object to create this distributed architecture. (Figure 10.)

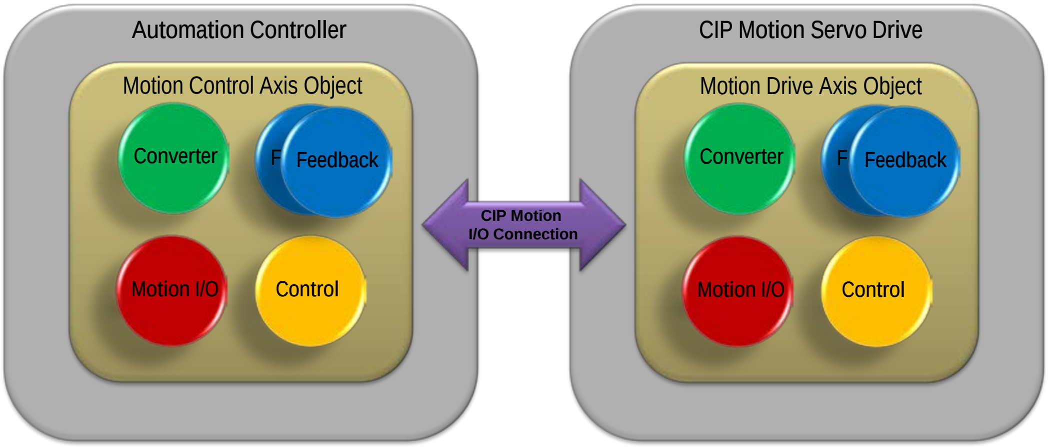

Figure 10

One example of a function that historically, has been packaged with the drive is the auxiliary feedback port. Traditionally, this function is embedded in every drive on the chance that it will be needed for that given application. In reality, in camming or line-shafting applications a single encoder on the primary axis can be shared by all through a CIP Motion multicast connection. Since it is so infrequently used, it can be eliminated in future drive designs, replaced when needed by a dedicated standalone CIP Motion Encoder device.

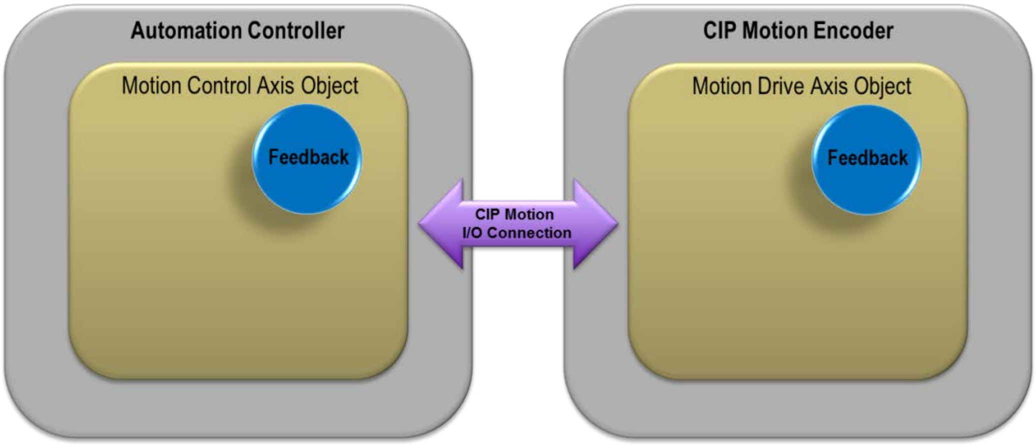

Figure 11

The object model shown above (Figure 11) illustrates the relationship between the Motion Control Axis Object and the Motion Drive Axis Object. In this case, the attributes for the CIP Motion Encoder Device already exist in the Motion Device Axis Object specification and consist of a relatively small subset of axis attributes that are applicable to the feedback function. These attributes are easily identified in the Motion Device Axis Object implementation table under the 'E' Device Control Code. See the table below, (Figure 12) which is an extract from the CIP Motion specification:

Instance Attribute			**Implementation by Device Control Code**					
Attr. ID	**Acc. Rule**	**Attribute Name**	**E**	**F**	**P**	**V**	**T**	**Conditional Implementation**
1351	Set	Induction Motor Rotor Leakage Reactance	-	R	R	R	R	Induction Motor only
1352	Set	Induction Motor Rated Slip Speed	-	O	O	O	O	Induction Motor only
1400 + o	Get	Feedback n Catalog Number	O	-	O	O	O	E
1401 + o	Get	Feedback n Serial Number	O	-	O	O	O	E
1402 + o	Get	Feedback n Position	R	-	R	R	R	E
1403 + o	Get	Feedback n Velocity	R	-	R	R	R	E
1404 + o	Get	Feedback n Acceleration	R	-	R	R	R	E
42	Set*	Feedback Mode	R	R	R	R	R	

Figure 12 (E = CIP Motion Encoder Device)

Position data produced by the external CIP Motion Encoder can then be consumed by the associated drive via a CIP Motion Peer Connection to provide auxiliary feedback functionality when needed. Figure 13 below shows how the CIP Motion Encoder Device would produce the position data to the Peer Connection.

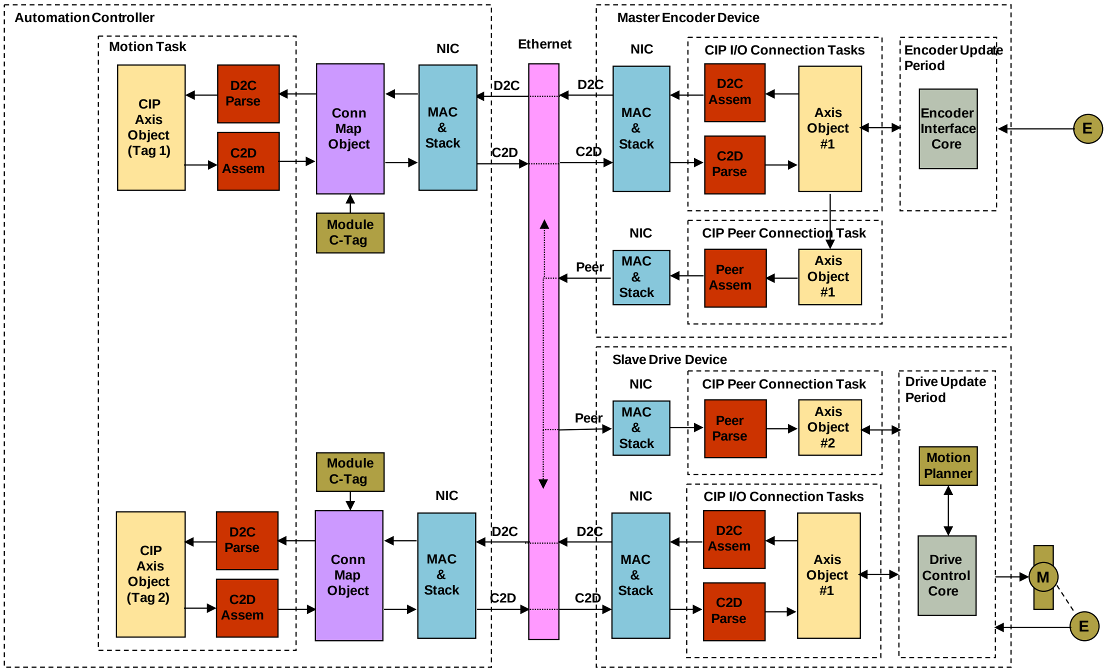

Figure 13

Another class of CIP Motion devices created by distributing motion functionality are CIP Motion I/O devices. Two very useful devices of this kind would be the CIP Motion Output Cam device, and the CIP Motion Registration Input device. See the object relationship model below, (Figure 14.)

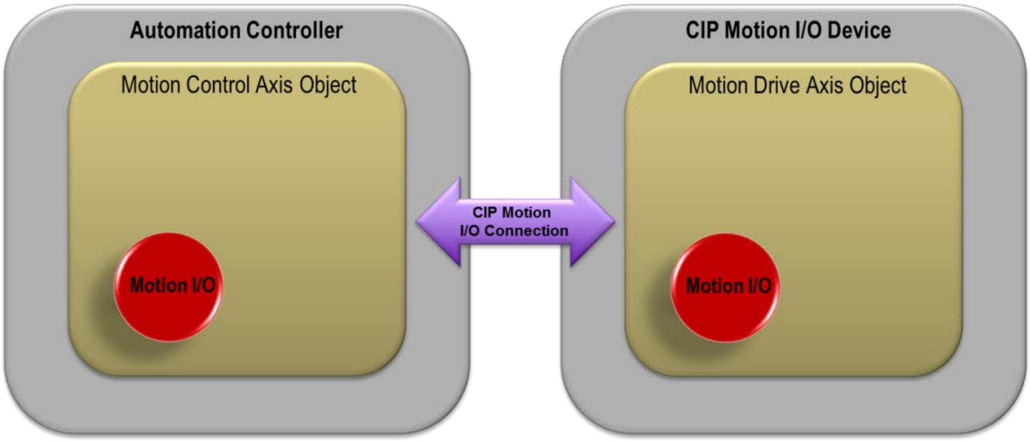

Figure 14

Similar to distributed CIP Motion Encoder the Motion Axis Object for this new CIP Motion I/O device would consist of a relatively small subset of axis attributes that are applicable to the CIP Motion Axis Object’s I/O functionality. These attributes may be identified in the Motion Device Axis Object implementation table under the ‘IO’ Device Control Code. See the table below, (Figure 15) an extract from the CIP Motion specification:

Instance Attribute			Implementation by Device Control Code						
Attr. ID	**Acc. Rule**	**Attribute Name**	**IO**	**E**	**F**	**P**	**V**	**T**	**Conditional Implementation**
1434 + o	Set	Feedback n Velocity Filter Bandwidth	-	O	-	O	O	O	
1435 + o	Set	Feedback n Accel Filter Bandwidth	-	O	-	O	O	O	
60	Set*	Event Checking Control	R	R	-	R	O	O	
61	Get	Event Checking Status	R	R	-	R	O	O	
62	Get	Registration 1 Positive Edge Position	O	O	-	R	O	O	
63	Get	Registration 1 Negative Edge Position	O	O	-	R	O	O	
64	Get	Registration 2 Positive Edge Position	O	O	-	O	O	O	
65	Get	Registration 2 Negative Edge Position	O	O	-	O	O	O	
66	Get	Registration 1 Positive Edge Time	O	O	-	R	O	O	
67	Get	Registration 1 Negative Edge Time	O	O	-	R	O	O	
68	Get	Registration 2 Positive Edge Time	O	O	-	O	O	O	
69	Get	Registration 2 Negative Edge Time	O	O	-	O	O	O	

Figure 15 (IO = CIP Motion I/O attributes)

A CIP Motion Output Cam device would consume real time Position data from a CIP Motion controller or device over the CIP Motion Peer Connection. (See Figure 16, below.)

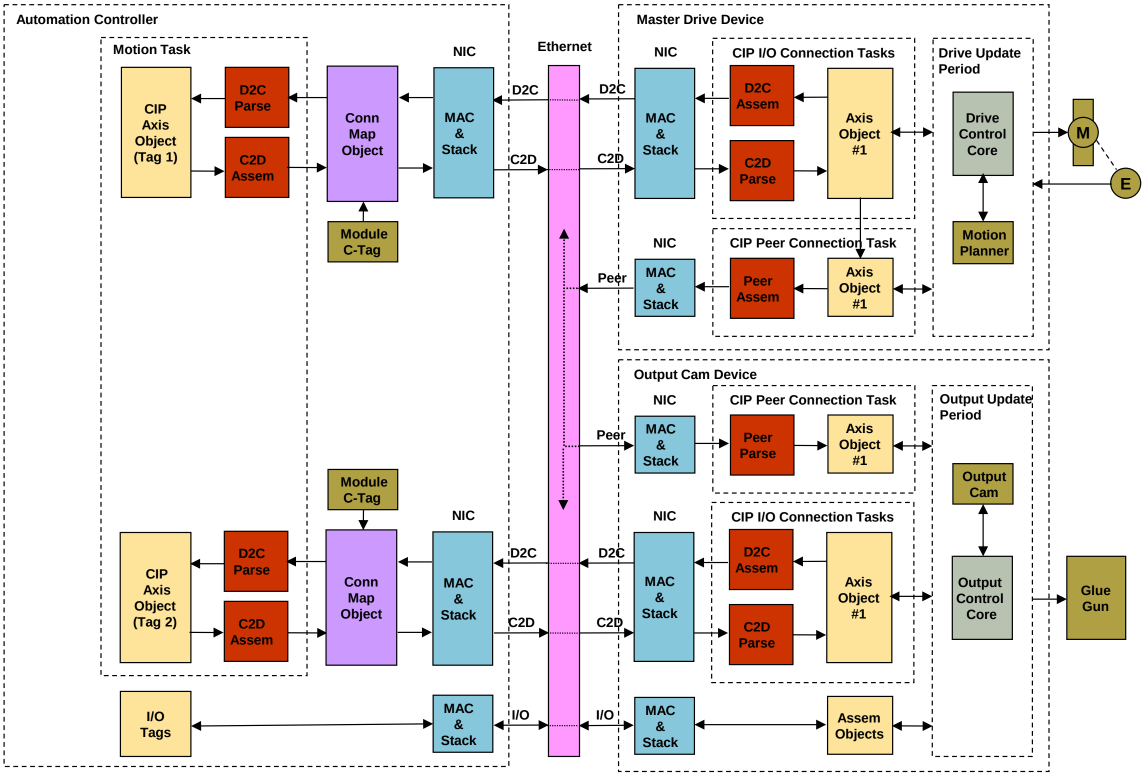

Figure 16

A CIP Motion Registration Input device would consume real time Position data from a producing CIP Motion controller or device over the CIP Motion Peer Connection. (See Figure 17 below.)

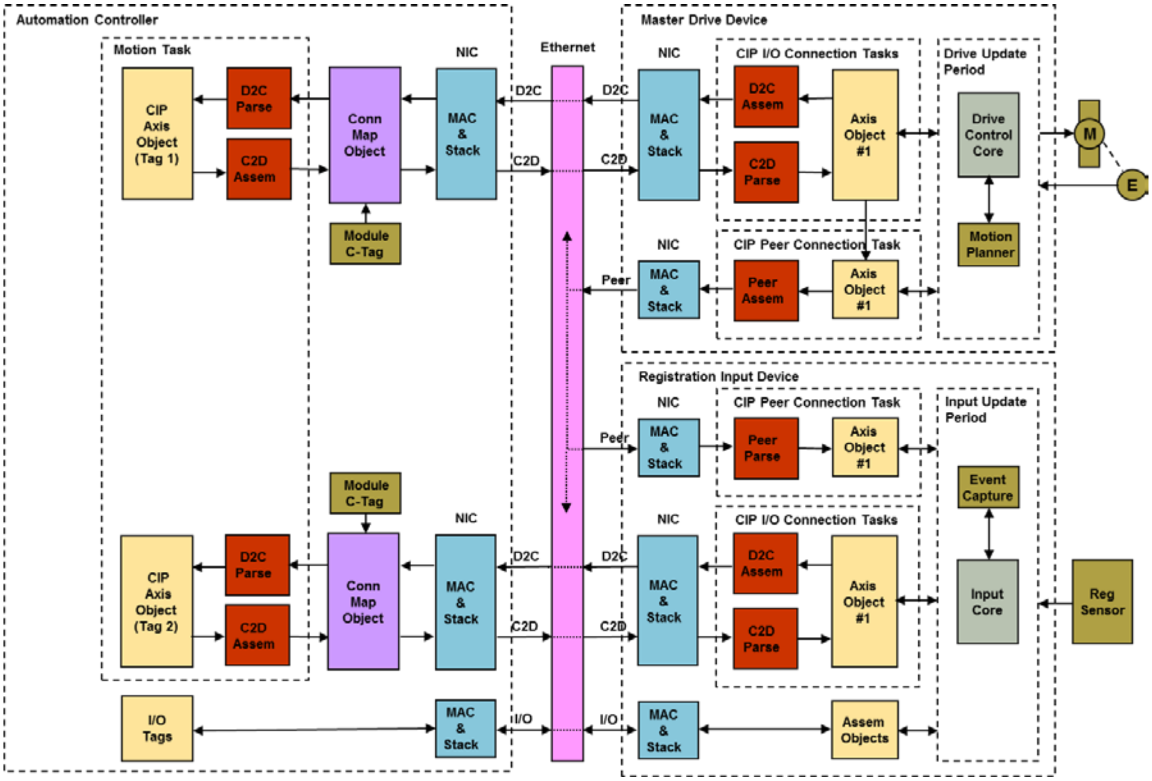

Figure 17

Converters (power supplies) previously built into every standalone drive are being eliminated in lean drive designs, replaced by a single, cost effective, standalone converter module supplying DC bus power to multiple inverter-only drives. (See Figure 18 below.)

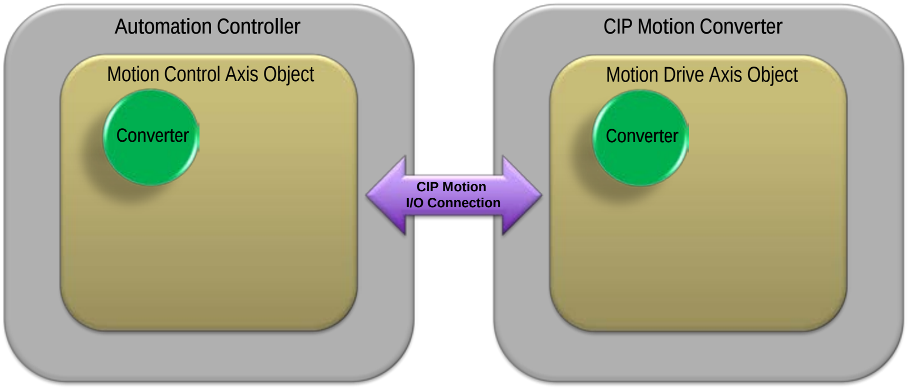

Figure 18

The Motion Axis Object for this CIP Motion Converter device would consist of a relatively small subset of axis attributes that are applicable to the converter power supply function. These attributes may be easily identified in the Motion Device Axis Object implementation table under the ‘B’ Device Control Code. (Reference Figure 19, below.)

Instance Attribute			Implementation by Device Control Code						
Attr. ID	Acc. Rule	Attribute Name	B	E	F	P	V	T	Conditional Implementation
614	Set	Mechanical Brake Control	-	-	O	O	O	O	
615	Set	Mechanical Brake Release Delay	-	-	O	O	O	O	
616	Set	Mechanical Brake Engage Delay	-	-	O	O	O	O	
620	Get	DC Bus Voltage	R	-	R	R	R	R	
621	Get	DC Bus Voltage - Nominal	R	-	R	R	R	R	
622	Set	Bus Configuration	O	-	O	O	O	O	
623	Set	Bus Voltage Select	-	-	R	R	R	R	
624	Set	Bus Regulator Action	R	-	R	R	R	R	
625	Set	Regenerative Power Limit	R	-	O	O	O	O	

Figure 19 (B = CIP Motion Converter device)

When the converter function is distributed to a standalone CIP Motion device, it still needs to communicate with the drives it is supplying DC bus power to so as to coordinate their operation with the converter's state. For example, if the converter becomes overheated, the converter needs to communicate an overload condition to the drives it is supplying power to so they can stop drawing from the DC Bus. The Distributed Motion architecture provides a solution to this communication problem by allowing the converter to be a Peer Connection producer and associated power consuming drives to be Peer Connection consumers of converter data. In this way, the converter can communicate status information to the associated drives, directly coordinating their behavior with the converter, without controller intervention. (See Figure 20 below.)

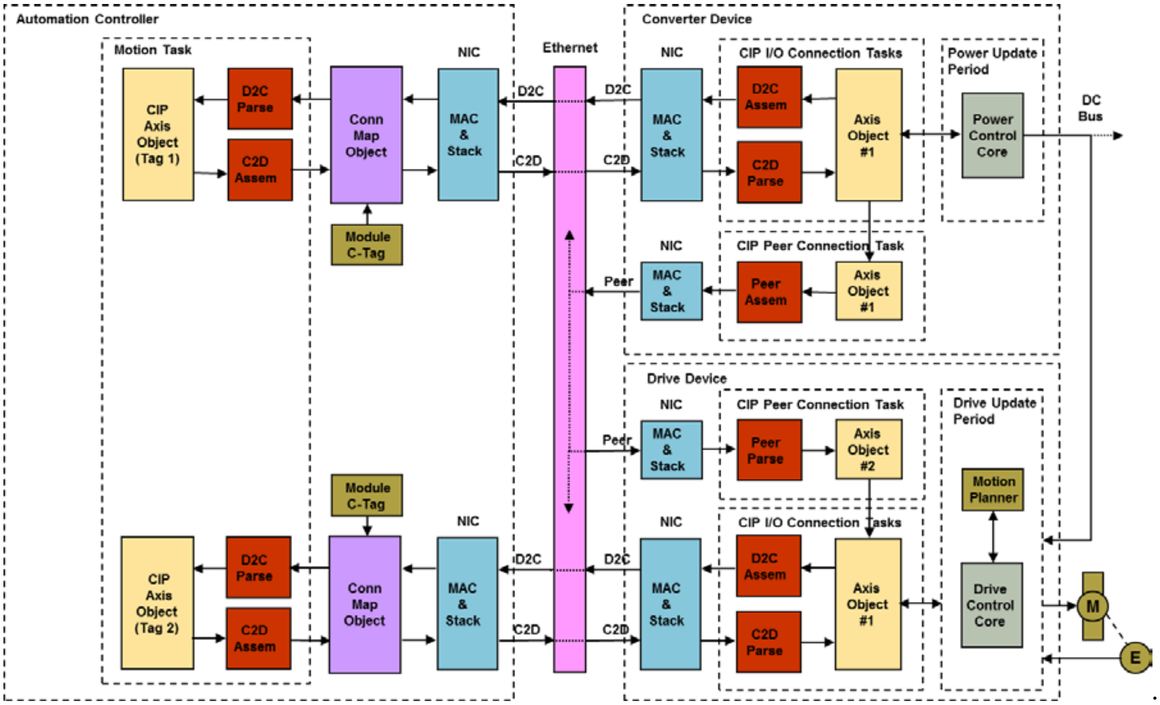

Figure 20

Conclusion

In this white paper we discussed how the Peer Connection enables a highly distributed and modular motion control architecture. This Peer Connection is un-intrusive in the system and easily layered across multi-vendor implementations - creating a unique, unifying real-time solution for electronic line shafting and camming applications. Today, no such solution exists in industry at this level of the network topology. The Peer Connection also allows motion planner execution to move from the controller to the drive, providing a major boost in overall system performance. Finally, the distribution of motion functions in the form of I/O devices, feedback sensors, and standalone converters (functionality that is already defined in today’s Motion Device Axis Object,) results in a clean, efficient and modular control architecture that is easily deployed and easily scaled.

In closing, the following table summarizes a few of the capabilities that the CIP Motion Peer Connection might enable in a motion system:

1.	Master axis produced / consumed information for distributed camming and gearing synchronization.
2.	Line controller machine motion coordination and synchronization via produced virtual axis.
3.	Synchronized robot operation - e.g. synchronized interpolation move execution using a common virtual axis master
4.	Drive torque sharing
5.	Inverter/Converter control synchronization
6.	Distributed drive I/O resources - Auxiliary feedback, registration,
7.	Distributed motion planning (drive based trajectory planner) with produced/consumed axis (master) driven synchronization

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The ideas, opinions, and recommendations expressed herein are intended to describe concepts of the author(s) for the possible use of CIP Networks and do not reflect the ideas, opinions, and recommendation of ODVA per se. Because CIP Networks may be applied in many diverse situations and in conjunction with products and systems from multiple vendors, the reader and those responsible for specifying CIP Networks must determine for themselves the suitability and the suitability of ideas, opinions, and recommendations expressed herein for intended use. Copyright ©2012 ODVA, Inc. All rights reserved. For permission to reproduce excerpts of this material, with appropriate attribution to the author(s), please contact ODVA on: TEL +1 734-975-8840 FAX +1 734-922-0027 EMAIL odva@odva.org WEB www.odva.org. CIP, Common Industrial Protocol, CIP Motion, CIP Safety, CIP Sync, CompoNet, CompoNet CONFORMANCE TESTED, ControlNet, ControlNet CONFORMANCE TESTED, DeviceNet, EtherNet/IP, EtherNet/IP CONFORMANCE TESTED are trademarks of ODVA, Inc. DeviceNet CONFORMANCE TESTED is a registered trademark of ODVA, Inc. All other trademarks are property of their respective owners.

Appendix A

The proposed data structure for the CIP Motion Peer Connection is as follows:

← 32-bit Word →

Peer Connection Format
Connection Header
Instance Header
Instance Data Block

Connection Header			
Connection Format	Format Revision	Update ID	Node Status
-	Node Fault/Alarm	-	Time Data Set
Producer Time Stamp			
Producer Time Offset			

Instance Data Block		
Instance Number	Cyclic Blk Size	Attr Blk Size
Cyclic Data Block		
Attribute Data Block		

Cyclic Data Block			
Control Mode	Feedback Mode	Axis State	Axis Config
Command Data Set	Actual Data Set	Status Data Set	Cyclic Data Control
Unwind			
Command Data 1			
Command Data 2			
…			
Actual Data 1			
Actual Data 2			
…			
Status Data 1			
Status Data 2			
…			

Attribute Data Block		
Cyclic Attr 1 ID	Attr 1 Dimension	Attr 1 Element Size
Attr 1 Start Index (array only)	Attr 1 Elements (array only)	
…	…	
Cyclic Attr 1 Data		
…		

The CIP Motion Peer Connection Format consists of a general header followed by a block of data associated with the produced axis instance. The content of the data block is periodically updated and sent to the consumers via a multicast connection at the specified Update Period of the producer. This update is synchronized with other peer devices in the motion control system through use of distributed System Time based on IEEE-1588 PTP. Since a Time Stamp is included in the connection data, the producer update rate does not need to have any fixed relationship with the update rates of the various consumers. Note that, unlike the CIP Motion I/O Connection, the CIP Motion Peer Connection is a one-way connection from producer to consumer with no return connection from the consumers. The implication of unidirectional data flow from producer to consumer is that there is no mechanism to support handshaking. For this reason, the CIP Motion Peer Connection does not support event notification/acknowledge exchanges or service request/response exchanges. These functions when needed can be readily facilitated via a separate CIP I/O connection.