

MTConnect Standard

Part 2 – Components and Data Items  
Version 1.1.0

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MTConnect Specification

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# Overview

MTConnect is a standard based on an open protocol for data integration. MTConnect is not intended to replace the functionality of existing products, but it strives to enhance the data acquisition capabilities of devices and applications and move toward a plug-and-play environment to reduce the cost of integration.

MTConnect is built upon the most prevalent standards in the manufacturing and software industry, maximizing the number of tools available for its implementation and providing the highest level of interoperability with other standards and tools in these industries.

To facilitate this level of interoperability, a number of objectives are being met. Foremost is the ability to transfer data via a standard protocol which includes:

* + A device identity (i.e. model number, serial number, calibration data, etc.).
  + The identity of all the independent components of the device.
  + Possibly a device’s design characteristics (i.e. axis length, maximum speeds, device thresholds, etc.).
  + Most importantly, data captured in real or near-real-time (i.e. current speed, position data, temperature data, program block, etc.) by a device that can be utilized by other devices or applications (e.g. utilized by maintenance diagnostic systems, management production information systems, CAM products, etc.).

The types of data that may need to be addressed in MTConnect could include:

* + Physical and actual device design data
  + Measurement or calibration data
  + Near-real-time data from the device

To accommodate the vast amount of different types of devices and information that may come into play, MTConnect will provide a common high-level vocabulary and structure.

The first version of MTConnect will focus on a limited set of the characteristics mentioned above that were selected based on the fact that they can have an immediate affect on the efficiency of operations.

## MTConnect Document Structure

The MTConnect specification is subdivided using the following scheme:

Part 1: Overview and Protocol

Part 2: Components and Data Items

Part 3: Streams, Events and Samples

Extensions to the standard will be made according to this scheme and new sections will be added as new areas are addressed. Documents will be named as follows: MTC\_Part\_<Number>\_<Description>.doc. All documents will be developed in Microsoft® Word format and released in Adobe® PDF format. For example, this document is MTC\_Part\_1\_Overview.doc.

# Purpose of This Document

This document is intended to:

* define the MTConnect standard;
* specify the requirements for compliance with the MTConnect standard;
* provide engineers with sufficient information to implement Agents for their devices;
* provide developers with the necessary guidelines to use the standard to develop applications.

Part 2 of the MTConnect standard focuses on structure and description of what information is available from the device. The actual device state is not provided in this section, but is covered in Part 3 covering streams, samples, and events. The descriptive data is similar to the schema of the data, it describes the components available in this devices and what data items are provided by each component.

This part also covers instructions on how a machine tool should be modeled, the structure of the component hierarchy, the names for each component (if restricted), and allowable data items for each of the component. Some components, like Linear axis, use the naming conventions as laid out in this document. This allows for a consistent meaning across devices.

## Terminology

**Adapter** An optional software component that connects the Agent to the Device.

**Agent** A process that implements the MTConnect specification, acting as an interface to the device.

**Alarm** An alarm indicates an event that requires attention and indicates a deviation from normal operation.

**Application** A process or set of processes that access the MTConnect Agent to perform some task.

**Attribute** A part of an element that provides additional information about that element. For example, the name element of the Device is given as <Device **name=“mill-1”**>...</Device>

**CDATA** The text in a simple content element. For example, *This is some text*, in <mt:Alarm ...>This is some text</mt:Alarm>.

**Component** A part of a device that can have sub-components and data items. A component is a basic building block of a device.

**Controlled Vocabulary** The value of an element or attribute is limited to a restricted set of possibilities. Examples of controlled vocabularies are country codes: US, JP, CA, FR, DE, etc…

**Current** A snapshot request to the Agent to retrieve the current values of all the data items specified in the path parameter. If no path parameter is given, then the values for all components are provided.

**Data Item** A data item provides the descriptive information regarding something that can be collected by the Agent.

**Device** A piece of equipment capable of performing an operation. A device is composed of a set of components that provide data to the application. The device is a separate entity with at least one Controller managing its operation.

**Discovery** Discovery is a service that allows the application to locate Agents for devices in the manufacturing environment. The discovery service is also referred to as the *Name Service.*

**Element** An XML element is the central building block of any XML Document. For example, in MTConnect the Device element is specified as <**Device** >...</**Device**>

**Event** An event represents a change in state that occurs at a point in time. Note: An event does not occur at predefined frequencies.

**HTTP** Hyper-Text Transport Protocol. The protocol used by all web browsers and web applications.

**Instance** When used in software engineering, the word *instance* is used to define a single physical example of that type. In object-oriented models, there is the class that describes the thing and the instance that is an example of that thing.

**LDAP** Lightweight Directory Access Protocol, better known as Active Directory in Microsoft Windows. This protocol provides resource location and contact information in a hierarchal structure.

**MIME** Multipurpose Internet Mail Extensions. A format used for encoding multipart mail and http content with separate sections separated by a fixed boundary.

**Probe** A request to determine the configuration and reporting capabilities of the device.

**REST** REpresentational State Transfer. A software architecture where the client and server move through a series of state transitions based solely on the request from the client and the response from the server.

**Results** A general term for the Samples and Events contained in a ComponentStream as a response from a sample or current request.

**Sample** A sample is a data point from within a continuous series of data points. An example of a Sample is the position of an axis.

**Socket** When used concerning interprocess communication, it refers to a connection between two end-points (usually processes). Socket communication most often uses TCP/IP as the underlying protocol.

**Stream** A collection of events and samples organized by devices and components.

**Service** An application that provides necessary functionality.

**Tag** Used to reference an instance of an XML element.

**TCP/IP** TCP/IP is the most prevalent stream-based protocol for interprocess communication. It is based on the IP stack (Internet Protocol) and provides the flow-control and reliable transmission layer on top of the IP routing infrastructure.

**URI** Universal Resource Identifier. This is the official name for a web address as seen in the address bar of a browser.

**UUID** Universally unique identifier.

**XPath** XPath is a language for addressing parts of an XML Document. See the XPath specification for more information. <http://www.w3.org/TR/xpath>

**XML** Extensible Markup Language. <http://www.w3.org/XML/>

**XML Schema** The definition of the XML structure and vocabularies used in the XML Document.

**XML Document** An instance of an XML Schema which has a single root element and conforms to the XML specification and schema.

## Terminology and Conventions

Please refer to Part 1 “Overview and Protocol” Section 2 for XML Terminology and Documentation conventions.

# Devices and Components

A device can be thought of as a group of components. For example, the Device is a three axis mill. The mill has components, one of the components is a Power component, often thought of as the main power supply. The mill also has sub-components of the Axes component; these are the three Linear axes and a Rotary axis. The Controller component controls the axes and runs the program using a single Path component. These are all sub-components of the Device.

For example, this three axis mill is modeled as a device that has a power supply, a controller, three linear axes and rotary axis representing the spindle:

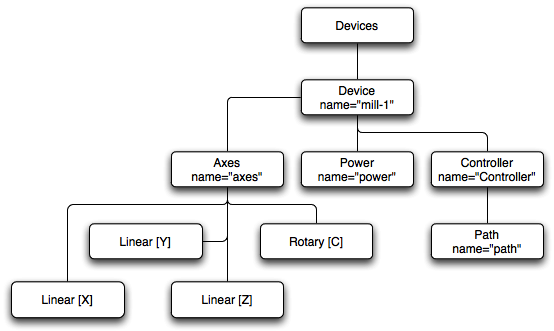


Figure : Example Devices Structure

Multiple devices may be represented in a top level container element called Devices. These container elements have no additional attributes and are only used to group sub-elements together. There are three containers used in the MTConnectDevices document. The first is the Devices element that contains all Device elements. The next container is the Components container that groups all the subcomponents together, like the Linear and Rotary. The last container is the DataItems container that groups all data items for a component together.

In the following document structure:  
 MTConnectDevices  
 Devices  
 Device  
 Components  
 Axes  
 Components  
 Rotary [C]

Values SPINDLE  
 Linear [X]  
 DataItems  
 DataItem [Xpos]  
 Linear [Y]  
 DataItems  
 DataItem [Ypos]  
 Linear [Z]  
 DataItems  
 DataItem [Zpos]  
  
 Controller

Components

Path  
 DataItems  
 DataItem [mode]  
 DataItem [execution]

These containers make it easier to address individual parts of the XML document. For example, if one wanted to retrieve just the DataItems for the Controller you can express this using the following XPath: //Controller/DataItems/\*. If you were interested in retrieving only the subcomponets of the Axes component, you would write the following XPath: //Axes/Components/\*.

All Devices, Components, and DataItems require an id attribute. The id attribute must adhere to the w3c standard ID-type and must be unique for the entire in an XML document. The id attributes **MUST** start with a :, \_, or letter (A-Z, a-z) and then may be followed with numbers, letters, -, or a period (.). For more information see: http://www.w3.org/TR/REC-xml/#NT-Name.

## Devices

The Devices element is a top level container for all Devices that is returned from a probe request. The probe response will only return an XML document that is a valid MTConnectDevices document.

| **Elements** | **Description** | **Occurrence** |
| --- | --- | --- |
| Device | The root of each device. The Device is contained within the top level Devices container. There can be multiple Device elements. | 1..INF |

## Component

The Agent needs to be capable of delivering data associated with each component to an application. The description of these pieces of information is referred to as DataItems and will be discussed in the section 4 of this document. The actual values for those data items are delivered in Streams and will be discussed in Part 3 of the standard on *Streams, Samples, and Events*.

## Component Schema



Figure : Component Schema

### Common Component Attributes

Every component has the following composition:

| **Attribute** | **Description** | **Occurrence** |
| --- | --- | --- |
| uuid | A unique identifier that will only refer to this component. For example, this can be the manufacturer code and the serial number. The uuid should be alphanumeric and not exceeding 255 characters. An NMTOKEN XML type. | 0..1\* |
| name | The name of the component. This name should be unique within the machine to allow for easier data integration. An NMTOKEN XML type. | 1 |
| id | The unique identifier for this component in the document. An id must be unique across all the id attributes in the document. An XML ID-type. | 1 |
| sampleRate | The rate in seconds that data is obtained from the component. This is the number of milliseconds between data captures. If the sample rate is smaller than one millisecond, the number can be represented as a floating point number. For example, for one 100 microsecond sample rate would be 0.1. | 0..1\*\* |

Notes: \* The uuid **MUST** be provided for the Device, it is optional for all other components. \*\* The sampleRate is used to aid the application in interpolating values. This is the desired sample rate and may vary depending on the capabilities of the device.

### Component Elements

| **Element** | **Description** | **Occurrence** |
| --- | --- | --- |
| Description | An element that can contain any descriptive content. This can contain configuration information and manufacturer specific details. | 0..1 |
| Components | Sub-components of this component. | 0..1\* |
| DataItems | The data items this component provides. The data items are descriptions of the data events for reporting. | 0..1\* |

Notes: \*At least one of Components or DataItems **MUST** be provided.

#### Description

| **Attribute** | **Description** | **Occurrence** |
| --- | --- | --- |
| manufacturer | The name of the manufacturer of the component | 0..1 |
| serialNumber | The device’s serial number | 0..1 |
| station | The station the device is located at. When a device is part of a manufacturing unit or cell with multiple stations that share the same physical controller. | 0..1 |

The CDATA of the Description is any additional descriptive information the implementor chooses to include regarding the component.

#### Components

| **Element** | **Description** | **Occurrence** |
| --- | --- | --- |
| Component | One or more components. This can also include the subtypes of Component like Axes, Linear, Power, Thermostat, etc... | 1..INF |

#### DataItems

| **Element** | **Description** | **Occurrence** |
| --- | --- | --- |
| DataItem | Only elements of types DataItem can be specified | 1..INF |

## Types of Components

All the elements in Figure 1 on page 8 are subtypes of Component. A component is an abstract type that allows for extensibility. As the specification progresses more component types will be added to support new devices.

### Device

At the top of the component tree there **MUST** be the root element Device. A Device is a container that holds all the components associated with this piece of equipment. The Device **MUST** have an alarm data item that provides a place for all Device general alarms that cannot be assigned to a sub-component.

#### Device Attributes

| **Attribute** | **Description** | **Occurrence** |
| --- | --- | --- |
| iso841Class | The ISO 841 classification for the device. | 1 |

A device **MUST** be classified using one of the following identifiers from the ISO 841 specification. The following classification is taken from the appendix of the ISO 841 specification, please use the diagram that best matches the figures in the appendix of ISO 841. If there is no diagram that matches the device, use iso841Class=”1”. Please provide us with a diagram of your device and its respective components and we will attempt to create a new classification for the device.

| **MTC ISO 841 Classification** | **Description** | **Figure** |
| --- | --- | --- |
| 1 | Other (Device not included in list) |  |
| 2 | Parallel lathe (engine lathe) | A.2 |
| 3 | Twin turret lathe with programmable tailstock | A.3 |
| 4 | Vertical turning and boring lathe | A.4 |
| 5 | Milling machine with horizontal spindle | A.5 |
| 6 | Milling machine with vertical spindle (with W axis) | A.6 |
| 7 | Boring and milling machine with horizontal spindle | A.7 |
| 8 | Milling machine with vertical spindle | A.8 |
| 9 | Portal-type milling machine | A.9 |
| 10 | Gantry-type milling machine | A.10 |
| 11 | Planer-type horizontal boring machine | A.11 |
| 12 | Profile and contouring milling machine with movable table | A.12 |
| 13 | Profile and contour milling machine with horizontal spindle | A.13 |
| 14 | Profile and contour milling machine with tilting head | A.14 |
| 15 | Profile and contour milling machine with tilting table | A.15 |
| 16 | External cylindrical grinding machine | A.16 |
| 17 | Tool and cutter grinding machine | A.17 |
| 18 | Openside planer | A.18 |
| 19 | Vertical filament winding machine | A.19 |
| 20 | Horizontal filament winding machine | A.20 |
| 21 | Flame cutting machine | A.21 |
| 22 | Punch press | A.22 |
| 23 | Drafting machine | A.23 |
| 24 | Right-hand tube bender | A.24 |
| 25 | Surface grinding machine with vertical grinding wheel | A.25 |
| 26 | Cavity sinking EDM machine | A.26 |
| 27 | Surface grinding machine | A.27 |
| 28 | Coordinate measuring machine | A.28 |
| 29 | Press brake | A.29 |
| 30 | Wire electrical discharge machine | A.30 |
| 31 | Laser cutting machine | A.31 |
| 32… | Reserved for future use. |  |

#### Device Structure

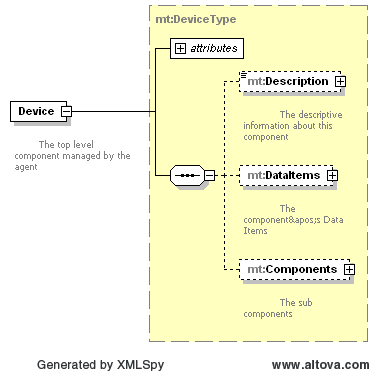


Figure : Device Schema Diagram

### Axes

There can be an arbitrary number of axes. This flexibility will accommodate the more complex multi-axis, multi-spindle machines in the future. An Axis can be one of two different types: Linear and Rotary. The Linear axes **MUST** be named X, Y, Z and U, V, W as defined in the ISO-841-2001 specification. Rotary axes **MUST** be named as A, B, and C and rotate around the Linear X, Y, and Z axes respectively as defined in ISO-841-2001.

The Axes represent the information as represented by the physical components. All position data **MUST** be presented in WORLD or MACHINE coordinates and not relative to the workpiece. The WORK coordinates will now be represented in the Path component of the Controller.

DEPRECATION WARNING: In version 1.2 of MTConnect, the Spindle component is no longer supported. The Spindle will now be represented by a rotary axis that has a RotaryMode of SPINDLE. The S axis nomenclature will be removed and replaced with A, B, or C to clearly identify which primary plane the spindle is rotating around. All data items **MUST** now be named accordingly.

*Note:* The convention to be used for multiple linear and rotary having the same designation is to index the letter with a number. For this standard the number starts at 2 (i.e. X, X2, X3, … or C, C2, C3, C4, …). This is in compliance with the ISO-841-2001. Please refer to that specification for more details.

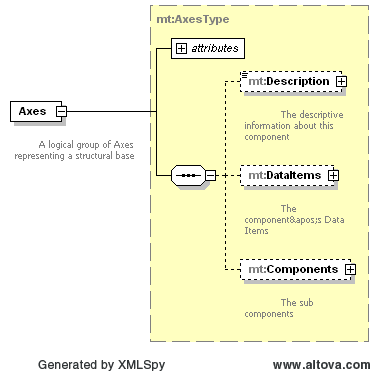


Figure : Axes Schema Diagram

The Axes component **MUST** contain at least one Axis component. The possible axis components are as follows:



Figure : Axes Example With Three Linear Axes and one Rotary Axis

**Linear** A linear axis moves in the direction parallel to the motion direction of a linearly moving component. Because of various errors, the direction of the linear axis can best be defined as a least-squared fit of a straight line to the appropriate straightness data.

**Rotary** An axis whose function is to provide rotary motion either for the purposes of positioning and can be used for continuous-path contour cutting in a rotary direction or for repositioning different faces of the part for the purpose of metal removal. A rotary axis can operate in one of the three following modes: SPINDLE, INDEX, or CONTOUR.

### Controller

The Controller component represents the CNC (Computer Numerical Control) or PAC (Programmable Automation Control) which has been referred to as a *Motion Control* or *General Purpose Motion Control*. The Control provides information regarding the execution of a control program and the execution state of the device. There are no required sub-components of the Controller.

### Path

For more complex devices and controllers, each path will be represented by a Path component. A Path represents the motion of a tooltip as it moves through space as controlled by a set of control instructions. The Path will encapsulate the position, feedrate, and rotation of the tooltip as presented by the controller.

### Power

The Power component is provided to report on the power status and possibly the voltage associated with its parent component. The device **MUST** contain a Power component and the Power component **MUST** contain the POWER\_STATUS data item. Any other data items **MAY** be added. Any other component, such as a Rotary, that can be switched on or off separately from the Device **SHOULD** have a Power component if this information is available.

Power **MUST** have a value of ON if the device is reachable and its power indicator is ON. A status of OFF means the power supply to the device has been disconnected. The one exception to this rule is if the Computer controller on the device is powered on but the rest of the device is powered off. In this case the device power status will still be considered OFF.

### Door

This component represents an opening that can be opened or closed. It **MUST** have a data item DoorStatus to indicate if it is opened or closed.

# Data Items

A DataItem describes a piece of information that can be collected from a component. The data item **MUST** specify the type of data being collected, the name of the data item, and the category of the item. There will only be one category for each type, but it **MUST** be included to aid the application in determining the location for the data stream. The data item **MAY** specify a Source sub-element to provide the native name for the data feed.

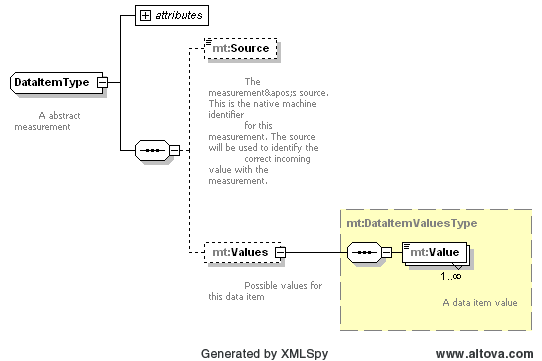


Figure : DataItem Schema Diagram

A DataItem **MAY** also specify the subType, to further qualify the type of data being requested. Subtypes are required for certain data itemsFor example, the POSITION has two subtypes: ACTUAL and COMMANDED. These are two separate data items that can be reported independently. See section 4.2.1 for a complete list of type/subtype relations.

The units **MUST** be specified for any numeric data type. The nativeUnits **MAY** be specified if they apply to the type of data and if they differ from the units. The Agent is responsible for converting the nativeUnits to the units before sending them to the applications. In addition, nativeUnits **MAY** be scaled using the nativeScale attribute; for example, if the device measures velocity in 100 ft/min, MTConnect would represent it with the following attributes: nativeUnits=“FEET/MINUTE” and nativeScale=“100”.

## DataItem Element

### Data Item Attributes

| **Attribute** | **Description** | **Occurrence** |
| --- | --- | --- |
| id | The unique identifier for this data item. The id attribute must be unique across the entire document including the ids for components. An XML ID-type. | 1 |
| name | The name of the data item. A data item will have a unique name within the component. If there are multiple data items of the same type, like Position, the name will distinguish the data item. An NMTOKEN XML type. | 1 |
| type | The type of data being measured. Examples of types are POSITION, VELOCITY, ANGLE, CODE, BLOCK, SPINDLE\_SPEED, etc. The types are part of a controlled vocabulary that is fixed version 1.0. | 1 |
| subType | A sub-categorization of the data item type. Examples of position subtypes of POSITION are ACTUAL and COMMANDED. Not all types have subtypes and this can be left off. The subtypes are part of a controlled vocabulary that is fixed in version 1.0. | 0..1 |
| category | This is how the data item will be sampled. The two options are SAMPLE and EVENT. | 1 |
| nativeUnits | The native units used by the component. These units will be converted before they are delivered to the application. | 0..1 |
| units | The units delivered to the application. These will always be the same for this data item type. This **MUST** be specified for all numeric values. | 0..1 |
| nativeScale | The multiplier for the native units. The received data **MAY** be divided by this value before conversion. If provided the value **MUST** be numeric. | 0..1 |
| significantDigits | The number of significant digits in the reported value. This is used by applications to determine accuracy of values. This **SHOULD** be specified for all numeric values. | 0..1 |
| coordinateSystem | The coordinate system being used. | 0..1 |

### Data Item Elements

| **Element** | **Description** | **Occurrence** |
| --- | --- | --- |
| Source | Source is an optional element that contains the long name of the data item if it is too complex for the name attribute. For example, if the data item has the name Xact and the axis position is delivered as Axis.channel.0.position from the device. The name attribute is Xact and the source is Axis.channel.0.position. If the source is not specified, it will be assumed to be the same as the name. | 0..1 |
| Values | The set of possible values this data item can be assigned. This provides a way to specify the capabilities for this component by limiting the choices. For example, for ROTARY\_MODE the axis can be limited to SPINDLE for an axis that can only spin. | 0..1 |

#### Values Elements

| **Element** | **Description** | **Occurrence** |
| --- | --- | --- |
| Value | A constraint on the possible values for this data item. If there is only one value listed here, the value data item will be constant. In the case of a constant data item, the value is not required to be supplied in the streams document. | 1..INF |

### Data Item attribute: category

MTConnect provides two different categories of data items, SAMPLE and EVENT. The category will indicate where the results will be reported in the XML Document as a response to a sample or current request. See Part 3 section 3 on *Streams, Samples, and Events* for more information.

**SAMPLE** A sample data item has a value that varies between different values in a manner that can be interpolated. A continuous value can be sampled at any point-in-time and will always produce a result. An example of a continuous data item is the Rotary C axis spindle speed. Sample data items that are continuous are always scalar floating point or integers that can have an infinite number of possible values. This is different from state or discrete data items that have a limited number of possible values.

**EVENT** Unexpected or discrete occurrence in a component. This includes state changes and alarms. Events do not have intermediate values that differ at intermediate times, as do samples.

### Data Item attribute: coordinateSystem

A data item can specify an optional coordinate system that is being used. If not specified, the Axes coordinates **MUST** be MACHINE and the Path coordinates **MUST** be WORK. The possible values of coordinates are:

**MACHINE** An unchangeable coordinate system that has machine zero as its origin.

**WORK** The position that acts as the origin for a particular workpiece.

### Data Item attribute: units

| **Unit** | **Description** |
| --- | --- |
| AMPERE | Amps |
| CELCIUS | Degrees Celsius |
| COUNT | A counted event |
| DEGREE | Angle in degrees |
| DEGREE/SECOND | Degrees per second |
| DEGREE/SECOND^2 | Acceleration in degrees per second squared |
| DEGREE\_3D | The three space angular rotation expressed in degree rotation around the X, Y, and Z axes (A, B, and C). |
| HERTZ | Frequency measured in cycles per second |
| KILOGRAM | Kilograms |
| LITER | Liters |
| MILLIMETER | Millimeters |
| MILLIMETER/SECOND | Millimeters per second |
| MILLIMETER/SECOND^2 | Acceleration in millimeters per second squared |
| MILLIMETER\_3D | A point in space in millimeters represented by a space delimited set of numbers |
| NEWTON | Force in newtons |
| PASCAL | Pressure in Newtons per square meter |
| PERCENT | Percent |
| REVOLUTION/MINUTE | Revolutions per minute |
| SECOND | A measurement of time. |
| STATUS | A status that conforms to the data item’s controlled vocabulary. Used in events to indicate states or status. |
| NEWTON\_METER | Torque, a unit for force times distance. The SI units will be used. |
| VOLT | Volts |
| WATT | Watts |

### Data Item attribute: nativeUnits

The nativeUnits attribute adds additional values to the units values. This is the list currently supported by MTConnect and the MTConnect schema.

| **Unit** | **Description** |
| --- | --- |
| INCH | Inches |
| INCH/MINUTE | Inches per minute |
| INCH/SECOND | Inches per second |
| INCH/SECOND^2 | Acceleration in inches per second squared |
| INCH\_3D | A point in space in inches represented by a space delimited set of numbers |
| FOOT | Feet |
| FOOT/MINUTE | Feet per minute |
| FOOT/SECOND | Feet per second |
| FOOT/SECOND^2 | Acceleration in feet per second squared |
| FOOT\_3D | A point in space in feet represented by a space delimited set of numbers |
| POUND | US pounds |
| FAHRENHEIT | Temperature in Fahrenheit |
| RADIAN | Angle in radians |
| RADIAN/SECOND | Velocity in radians per second |
| RADIAN/SECOND^2 | Rotational acceleration in radian per second squared |
| RADIAN/MINUTE | Velocity in radians per second. |
| RADIAN\_3D | The three space angular rotation expressed in radians rotation around the X, Y, and Z axes (A, B, and C). |
| MILLIMETER/MINUTE | Velocity in millimeters per minute |
| DEGREE/MINUTE | Rotational velocity in degrees per minute |
| REVOLUTION/SECOND | Rotational velocity in revolution per second |
| OTHER | Unsupported units |

## Types and Subtypes of Data Items

What follows is the association between the various types and subtypes of data items. Each data item type **MUST** be translated into a Sample or Event with the following rules: The type name will be all in capitals with an underscore (\_) between words. The element of the event or sample will be the transformation of the data item type by capitalizing the first character of each word and then removing the underscore. For example, the data item type POWER\_STATUS is PowerStatus, POSITION is Position, and SPINDLE\_SPEED is SpindleSpeed.

An example of this transformation between the DataItem name and the Stream element is as follows:

<Controller name="Controller" id="8">

<DataItems>

<DataItem type="**LINE**" category="EVENT" id="19" subType="**ACTUAL**" name="line" />

<DataItem type="**CONTROLLER\_MODE**" category="EVENT" id="20" name="mode" />

<DataItem type="PROGRAM" category="EVENT" id="21" name="program" />

<DataItem type="EXECUTION" category="EVENT" id="22" name="execution" />

<DataItem type="BLOCK" category="EVENT" id="23" name="block" />

</DataItems>

</Controller>

The transformation from the probe *(as defined in Part 1 of the standard)* to the current or sample will occur as follows. This also illustrates how the subType is also placed in the ComponentStream as well. The probe will provide the category meaning the sub-element of the ComponentStream the items will appear in. Also note how the CONTROLLER\_MODE was changed to ControllerMode in the current request below.

<ComponentStream componentId="8" component="Controller" name="Controller">

<Events>

<**Line** dataItemId="19" timestamp="2009-03-04T19:45:50.458305" subType="**ACTUAL**" name="line" sequence="150651130">702</Line>

<Block dataItemId="23" timestamp="2009-03-04T19:45:50.458305" name="block" sequence="150651134">x0.371524 y-0.483808</Block>

<**ControllerMode** dataItemId="20" timestamp="2009-02-26T02:02:35.716224" name="mode" sequence="182">AUTOMATIC</ControllerMode>

</Events>

</ComponentStream>

### Data Item Types for SAMPLE Category

The types are given in **bold** and the subtypes are indented and in plain text.

| **Data Item type/subtype** | **Description** | **Units** |
| --- | --- | --- |
| **ACCELERATION** | Rate of change of velocity | MILLIMETER/SECOND^2 |
| **ANGULAR\_ACCELERATION** | Rate of change of angular velocity. | DEGREE/SECOND^2 |
| **ANGULAR\_VELOCITY** | Rate of change of angular position. | DEGREE/SECOND |
| **AMPERAGE** | The line current | AMPERE |
| **ANGLE** | The angular position of a component relative to the parent. | DEGREE |
| * + ACTUAL | The angular position as read from the physical component. | DEGREE |
| * + COMMANDED | The angular position computed by the controller. | DEGREE |
| **AXIS\_FEEDRATE** | The feedrate of the axis. | MILLIMETER/SECOND |
| * + ACTUAL | The single dimension feedrate. | MILLIMETER/SECOND |
| * + COMMANDED | The feedrate as specified in the program. | MILLIMETER/SECOND |
| * + OVERRIDE | The operator’s overridden value. Percent of commanded. | PERCENT |
| **DISPLACEMENT** | The displacement as measured from zero to peak | MILLIMETER |
| **FREQUENCY** | The frequency as measure in cycles per second | HERTZ |
| **GLOBAL\_POSITION** | The position in three-dimensional space. The X, Y, and Z positions will be provided. | MILLIMETER |
| * + ACTUAL | The position of the component as read from the device. | MILLIMETER |
| * + COMMANDED | The position computed by the controller. | MILLIMETER |
| **LOAD** | The load on the component. | NEWTON |
| **PATH\_FEEDRATE** | The feedrate of the tool path. | MILLIMETER/SECOND |
| * + ACTUAL | The three-dimensional feedrate derived from all components. | MILLIMETER/SECOND |
| * + COMMANDED | The feedrate as specified in the program | MILLIMETER/SECOND |
| * + OVERRIDE | The operator’s overridden value. Percent of commanded. | PERCENT |
| **PATH\_POSITION** | The current three space tooltip position in WORK coordinates. | MILLIMETER\_3D |
| **PATH\_ROTATION** | The current three space angular rotation of the tooltip in WORK coordinates. | DEGREE\_3D |
| **PRESSURE** | The pressure on the component | PASCAL |
| **POSITION** | The position of the component. Defaults to machine coordinates. | MILLIMETER |
| * + ACTUAL | The position of the component as read from the device. | MILLIMETER |
| * + COMMANDED | The position as given by the Controller. | MILLIMETER |
| **SPINDLE\_SPEED** | The rotational speed of the rotary axis. | REVOLUTION/MINUTE |
| * + ACTUAL | The rotational speed the rotary axis is spinning at. ROTARY\_MODE must be SPINDLE. | REVOLUTION/MINUTE |
| * + COMMANDED | The rotational speed the as specified in the program. | REVOLUTION/MINUTE |
| * + OVERRIDE | The operator’s overridden value. Percent of commanded. | PERCENT |
| **TEMPERATURE** | The temperature | CELSIUS |
| **TORQUE** | The torque | NEWTON\_METER |
| **VELOCITY** | The rate of change of position. | MILLIMETER/SECOND |
| **VOLTAGE** | The voltage | VOLT |
| **WATTAGE** | The wattage | WATT |

### Data Item Types for EVENT Category

Note: The Event does not have any units since these values are not scalers.

| **Data Item type/subtype** | **Description** |
| --- | --- |
| **ALARM** | An alarm is a special data item that will report any alarm for this component. An alarm **MUST** be included as a DataItem for the Device |
| **BLOCK** | The block of code being executed. The block contains the entire expression of the step in the program. |
| **CODE** | The programmatic code being executed |
| **DOOR\_STATUS** | The opened or closed status of the door. OPEN or CLOSED. |
| **CONTROLLER\_MODE** | The current controller’s mode. AUTOMATIC, MANUAL, or  MANUAL\_DATA\_INPUT |
| **DIRECTION** | The rotational direction of the Axis. CLOCKWISE or COUNTER\_CLOCKWISE |
| **EXECUTION** | The execution status of the Controller. READY, ACTIVE, INTERRUPTED, or STOPPED |
| **LINE** | The current line of code being executed |
| **PART\_COUNT** | The current count of parts produced as represented by the controller. Must be an integer value. |
| ALL | The count of all the parts produced. If the subtype is not given, this is the default. |
| GOOD | Indicates the count of correct parts made. |
| BAD | Indicates the count of incorrect parts produced. |
| **PART\_ID** | An identifier of the current part in the device |
| **PATH\_MODE** | The operational mode for this path. SYNCHRONOUS, MIRROR, or INDEPENDENT. Default value is INDEPENDENT if not specified. |
| **POWER\_STATUS** | The ON or OFF status of the component. |
| **PROGRAM** | The name of the program being executed |
| **ROTARY\_MODE** | The mode for the Rotary axis. SPINDLE, INDEX, or CONTOUR. |
| **TOOL\_ID** | The identifier of the tool currently in use for a given path |
| **WORKHOLDING\_ID** | The identifier for the workholding currently in use for a given path |

# Component and Data Item Relationships

This section will discuss the association between Component, DataItems, and Events and Samples. For each component, there are a limited set of allowable sub-components and a limited set of data items. For example, an Axes component may not have a Device or a Controller as a child, and it may not have as a Block DataItem type, since it is incapable of running a program.

## Overview

At the top level, a device **MUST** always contain a Power component as the main power supply. Every component that is capable of managing its own power supply, **SHOULD** have a Power sub-component. For example, an axis **SHOULD** have a Power sub-component if it can be turned off separately from the device.

Any component **MAY** also include an arbitrary set of sensors as sub-components. The sensor is currently a placeholder for extensible data collection devices and is not modeled in this version of the specification. A sensor will be an external device that will collect data and report it to the Agent. The sensor **MUST** be correctly associated with its most relevant component. The rules governing this association will be covered in a later version of this specification.

## Device

The Device is the only top level element in the component tree. Since an MTConnect Agent can manage multiple devices, the schema provides a top level container Devices to hold the Device elements.

### DataItem types

* ALARM - An alarm placeholder for all alarms that are not associated with another component.

### Sub-components of Device

* Power
* Controller
* Axes

## Common Components and Data Items

### Axes

The Axes component serves two functions: it is a container for the actual axes as well the global data items for kinematics, path feedrate and other aggregates of all the Axis components below it. An Axes **MAY** have one or more of these:

#### DataItem types

* ~~GLOBAL\_POSITION~~ - DEPRECATED
* ~~PATH\_FEEDRATE~~ – Moved to Path
* ~~ACCELERATION~~ – Moved to Path
* ~~VELOCITY~~ – Moved to Path

#### Sub-components of Axes

* Linear
* Rotary
* ~~Spindle~~ - DEPRECATED

### Linear

A linear axis represents travel along a straight line. The name of the linear axis **SHOULD** follow the conventions of the industry.

#### DataItem types

* POSITION
* ACCELERATION
* VELOCITY
* LOAD
* AXIS\_FEEDRATE

### Rotary

A rotary axis revolves around a point.

#### DataItem types

* ANGLE
* ANGULAR\_ACCELERATION
* ANGULAR\_VELOCITY
* AXIS\_FEEDRATE
* DIRECTION
* LOAD
* ROTARY\_MODE
* TORQUE

### Controller

The controller component is the component that controls a device, executes a program, and sends instructions to the other components of the machine. It is the brains of the machine and can be asked for its current execution state and program name.

#### Sub-components of Controller

* Path

#### DataItem types

* ACTIVE\_AXES
* BLOCK
* CODE
* CONTROLLER\_MODE
* EXECUTION
* LINE
* PART\_COUNT
* PART\_ID
* PATH\_ANGLE
* PATH\_FEEDRATE
* PATH\_MODE
* PATH\_POSITION
* PROGRAM
* SLAVE\_AXES
* TOOL\_ID
* WORKHOLDING\_ID

### Path

The controller component is the component that controls a device, executes a program, and sends instructions to the other components of the machine. It is the brains of the machine and can be asked for its current execution state and program name.

#### DataItem types

* ACTIVE\_AXES
* BLOCK
* CODE
* CONTROLLER\_MODE
* EXECUTION
* LINE
* PART\_COUNT
* PART\_ID
* PATH\_ANGLE
* PATH\_FEEDRATE
* PATH\_MODE
* PATH\_POSITION
* PROGRAM
* SLAVE\_AXES
* TOOL\_ID
* WORKHOLDING\_ID

### Power

The power component represents the electrical activation of the component. The data items the power component can collect are a simple status (on/off) and three power related measurements, voltage, amperage and watts. There are no sub-components of Power. The reason for making this a separate component is the need to support legacy equipment.

For the top-level device Power component, the Power represents the power to all other components than the computer controller. Since the controller may be hosting the MTConnect *Agent*, it would be impossible to report Power OFF if the controller is off. If network or physical connectivity to the device is interrupted, the Power **MUST** be considered off.

For all other components, the definition of OFF is the component is not connected to the power source.

#### DataItem types

* POWER\_STATUS
* VOLTAGE
* AMPERAGE
* WATTS

### Thermostat

A sensor capable of measuring the temperature of a component. The temperature is always given in Celsius.

#### DataItem types

* TEMPERATURE

### Vibration

A sensor capable of measuring the vibration of a component.

#### DataItem types

* DISPLACEMENT
* FREQUENCY
* VELOCITY
* ACCELERATION

### Door

A opening that can be closed.

#### DataItem types

* DOOR\_STATUS

## ~~Cutting Machine Tool Components and Data Items~~

### ~~Spindle - DEPRECATED~~

~~The spindle is a rotational axis that revolves at high speed and has its speed expressed in REVOLUTION/MINUTE. The spindle can also have additional data items. Spindle speed has been specified as a separate data item since it receives special treatment in many applications. Velocity is used for linear axes other than spindle.~~

#### ~~DataItem types~~

* ~~SPINDLE\_SPEED~~
* ~~LOAD~~
* ~~DIRECTION~~
* ~~TORQUE~~

# Annotated XML Examples

## Simplest Device

For the simplest possible device we are modeling a saw that has only a power status (the minimal set of components). To retrieve this information we send the following request to the Agent:

[http://10.1.23.10/ LinuxCNC/probe](http://10.1.23.10/%20LinuxCNC/probe)

The Agent responds as follows:

1. <?xml version="1.0" encoding="UTF-8"?>
2. <MTConnectDevices xmlns:m="urn:mtconnect.com:MTConnectDevices:0.9" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="urn:mtconnect.com:MTConnectDevices:0.9" xsi:schemaLocation="urn:mtconnect.com:MTConnectDevices:0.9 /schemas/MTConnectDevices.xsd">
3. <Header sender="10.1.23.10" bufferSize="100000" creationTime="2008-07-07T23:07:50-07:00" version="0.9" instanceId="1214527986"/>

Line 3 provides the instanceId as a unique number for this run. For this example, the Agent does not persist the samples and events, therefore, this number will change every time. The bufferSize indicates that this Agent is capable of storing 100,000 samples and events.

1. <Devices>
2. <Device iso841Class="6" uuid="linux-01" name="LinuxCNC" sampleRate="100.0" id="d">
3. <Description manufacturer="NIST" serialNumber="01"/>

The above device description includes the unique id and a sample rate of ten times per second. Since there are no telemetry data being collected, once a second is adequate.

1. <DataItems>
2. <DataItem type="ALARM" name="alarm" category="EVENT" id="a"/>
3. </DataItems>

On line 8 we define the catch-all alarm for this device.

1. <Components>
2. <Power name="power" id="p">
3. <DataItems>
4. <DataItem type="POWER\_STATUS" name="power" category="EVENT" id="ps"/>
5. </DataItems>
6. </Power>

As was stated before, the device is only required to have one Power component which **MUST** report its status. The DataItem on line 13 has an id number of 9. This will allow events responding to this data item to be easily associated. One can also see that this has been categorized as an Event and the application should expect PowerStatus in the Events collection of the ComponentStream.

1. </Components>
2. </Device>
3. </Devices>
4. </MTConnectDevices>

## More Complex Example of probe

The sample was generated with the following request:

* http://10.1.23.5/LinuxCNC/probe

The following is an example of a 3 axis mill simulation. The mill has three linear axes and one spindle:

1. <?xml version="1.0" encoding="UTF-8"?>
2. <MTConnectDevices xmlns:m="urn:mtconnect.com:MTConnectDevices:0.9" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns="urn:mtconnect.com:MTConnectDevices:0.9" xsi:schemaLocation="urn:mtconnect.com:MTConnectDevices:0.9 /schemas/MTConnectDevices.xsd">
3. <Header sender="10.1.23.5" bufferSize="100000" creationTime="2008-07-07T23:07:50-07:00" version="0.9" instanceId="1214527986"/>
4. <Devices>
5. <Device iso841Class="6" uuid="linux-01" name="LinuxCNC" sampleRate="100.0" id="d1">

Here we provide the top level container Devices and the information on the Device.

1. <Description manufacturer="NIST" serialNumber="01"/>
2. <DataItems>
3. <DataItem type="ALARM" name="alarm" category="EVENT" id="a"/>
4. </DataItems>
5. <Components>
6. <Axes name="Axes" id="3">

On line 11 we introduce the collection of Axes. The Axes component is a special component that acts as an abstract component as well as a collection. The Axes component contains various data items that have a global context; they are not associated with any one data item, but they go across all axes.

1. <Components>
2. <Rotary name="C" id="c1">
3. <DataItems>
4. <DataItem type="SPINDLE\_SPEED" name="Cspeed" category="SAMPLE" id="c2" nativeUnits="REVOLUTION/MINUTE" subType="ACTUAL" units="REVOLUTION/MINUTE">
5. <Source>Sspeed</Source>
6. </DataItem>
7. <DataItem type=”ROTARY\_MODE” name”Cmode” category=”EVENT” id=”c3”>
8. <Values><Value>SPINDLE</Value><Values>
9. </DataItem>
10. </DataItems>
11. </Rotary>

The spindle component declared on line 16 is the S axis and has spindle-specific data items.

1. <Linear name="X" id="x1">
2. <DataItems>
3. <DataItem type="POSITION" name="Xact" category="SAMPLE" id="x2" nativeUnits="MILLIMETER" subType="ACTUAL" units="MILLIMETER"/>
4. <DataItem type="POSITION" name="Xcom" category="SAMPLE" id="x3" nativeUnits="MILLIMETER" subType="COMMANDED" units="MILLIMETER"/>
5. </DataItems>
6. </Linear>
7. <Linear name="Y" id="y1">
8. <DataItems>
9. <DataItem type="POSITION" name="Yact" category="SAMPLE" id="y2" nativeUnits="MILLIMETER" subType="ACTUAL" units="MILLIMETER"/>
10. <DataItem type="POSITION" name="Ycom" category="SAMPLE" id="y3" nativeUnits="MILLIMETER" subType="COMMANDED" units="MILLIMETER"/>
11. </DataItems>
12. </Linear>
13. <Linear name="Z" id="z1">
14. <DataItems>
15. <DataItem type="POSITION" name="Zact" category="SAMPLE" id="z2" nativeUnits="MILLIMETER" subType="ACTUAL" units="MILLIMETER"/>
16. <DataItem type="POSITION" name="Zcom" category="SAMPLE" id="z3" nativeUnits="MILLIMETER" subType="COMMANDED" units="MILLIMETER"/>
17. </DataItems>
18. </Linear>

Lines 24, 30, and 36 define the three linear axes X, Y, and Z respectively. In this example device the Agent is only collecting the actual and commanded positions.

1. </Components>
2. </Axes>

The Controller is capable of providing the program name, block, and the current line being executed:

1. <Controller name="Controller" id="8">
2. <Components>
3. <Path id=”p1” name=”path”>
4. <DataItems>
5. <DataItem type="LINE" name="line" category="EVENT" id="p1"/>
6. <DataItem type="CONTROLLER\_MODE" name="mode" category="EVENT" id="p2"/>
7. <DataItem type="PROGRAM" name="program" category="EVENT" id="p3"/>
8. <DataItem type="EXECUTION" name="execution" category="EVENT" id="p4"/>
9. <DataItem type="PATH\_FEEDRATE" name="feedrate" category="SAMPLE" id="p4" units=”MILLIMETER/SECOND” nativeUnits=”MILLIMETER/SECOND” />
10. <DataItem type="PATH\_POSITION" name="position" category="SAMPLE" id="p4" units=”MILLIMETER\_3D” nativeUnits=”INCH\_3D”/>
11. </DataItems>
12. </Path>
13. </Components>
14. </Controller>
15. <Power name="power" id="w1">
16. <DataItems>
17. <DataItem type="POWER\_STATUS" name="power" category="EVENT" id="w2"/>
18. </DataItems>
19. </Power>
20. </Components>
21. </Device>
22. </Devices>
23. </MTConnectDevices>

# Bibliography

1. Engineering Industries Association. *EIA Standard - EIA-274-D*, Interchangeable Variable, Block Data Format for Positioning, Contouring, and Contouring/Positioning Numerically Controlled Machines. Washington, D.C. 1979.
2. ISO TC 184/SC4/WG3 N1089. *ISO/DIS 10303-238*: Industrial automation systems and integration Product data representation and exchange Part 238: Application Protocols: Application interpreted model for computerized numerical controllers. Geneva, Switzerland, 2004.
3. International Organization for Standardization. *ISO 14649*: Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Part 10: General process data. Geneva, Switzerland, 2004.
4. International Organization for Standardization. *ISO 14649*: Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Part 11: Process data for milling. Geneva, Switzerland, 2000.
5. International Organization for Standardization. *ISO 6983/1* – Numerical Control of machines – Program format and definition of address words – Part 1: Data format for positioning, line and contouring control systems. Geneva, Switzerland, 1982.
6. Electronic Industries Association. *ANSI/EIA-494-B-1992*, 32 Bit Binary CL (BCL) and 7 Bit ASCII CL (ACL) Exchange Input Format for Numerically Controlled Machines. Washington, D.C. 1992.
7. National Aerospace Standard. *Uniform Cutting Tests* - NAS Series: Metal Cutting Equipment Specifications. Washington, D.C. 1969.
8. International Organization for Standardization. *ISO 10303-11*: 1994, Industrial automation systems and integration Product data representation and exchange Part 11: Description methods: The EXPRESS language reference manual. Geneva, Switzerland, 1994.
9. International Organization for Standardization. *ISO 10303-21*: 1996, Industrial automation systems and integration -- Product data representation and exchange -- Part 21: Implementation methods: Clear text encoding of the exchange structure. Geneva, Switzerland, 1996.
10. H.L. Horton, F.D. Jones, and E. Oberg. *Machinery's handbook*. Industrial Press, Inc. New York, 1984.
11. International Organization for Standardization. *ISO 841-2001: Industrial automation systems and integration - Numerical control of machines - Coordinate systems and motion nomenclature.* Geneva, Switzerland, 2001.
12. *ASME B5.59-2 Version 9c: Data Specification for Properties of Machine Tools for Milling and Turning. 2005.*
13. *ASME/ANSI B5.54: Methods for Performance Evaluation of Computer Numerically Controlled Lathes and Turning Centers. 2005.*
14. OPC Foundation. *OPC Unified Architecture Specification, Part 1: Concepts Version 1.00. July 28, 2006.*