The Semantics of Measured Quantities

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NCSL International 141 MII and Automation Committee

Measurement-Information Infrastructure

Section 1

Introduction

Today's Topics

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2. Quantity Kinds and the M-Layer

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2. Quantity Kinds and the M-Layer
3. Measurands and the MII Taxonomy

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Acronyms

- SoA—scope of accreditation
- DCC—digital calibration certificate (PTB)
- CMC—calibration and measurement capability
- KCDB—key comparison database
- NCSLI—NCSL International
- FAIR—findable, accessible, interoperable, reusable
- M-Layer—metrology information layer to support measurement systems

Definition

MII (measurement information infrastructure)
—set of normative standards that unambiguously define data structures, taxonomies, service protocols and security for locating, communicating and sharing measurement information

Incremental Progress toward an Ideal DCC

DCC development strategy advantages:

- Target an easy transition—increases adoption rate
- Quick results and incremental progress—no inordinate delays for the "perfect" DCC
- Pareto coverage—widest applicability in the shortest time

Some (future) ideal DCC elements:

- Unique equipment class IDs, e.g.
- A universal measurement-results model
- Rich, detailed traceability
- Machine-actionable measurement results

Toward Machine-Actionable Measurement Results

Distinct quantity concepts and representation levels

1. Quantity kind: most general, associated with measurement units, e.g. length
   - Applies to all quantity values, including uncertainties
   - Unique quantity IDs for unambiguous quantities
   - Unambiguous scales & units to handle any measurement arena
2. Measurand: most specific, the desired measured quantity, e.g., inner diameter
   - Metadata for measurement results in DCCs, functions in instrument specs, CMCs in accreditation statements and the KCDB
   - Unique measurand IDs
3. Semantically qualified: ontologically augmented quantities
   - Applies to machine-actionable operations
   - Smart calculations, unguided derivations

Section 2

Quantity Kinds and the M-Layer

Quantity Kinds

- Associated with quantity values and measurement units: $L = 1\,\mathrm{m}$
- Group references and expression conversions: $1\,\mathrm{m} = 100\,\mathrm{cm}$
- Explicitly or implicitly used in all sciences and applications
- Problems for machines:
  - Units do not always capture the quantity kind (10°: optical incidence or phase angle? Dimensionless quantities? $12\,\mathrm{N\,m}$: torque or energy? ...).
  - Free-form text descriptions do not suffice.
  - Scales not explicitly distinguished ($5\,^\circ\mathrm{C}$: absolute temperature or temperature interval?)
  - Uncontrolled scale operations ($2\,^\circ\mathrm{C} + 1\,^\circ\mathrm{C} = ?$)

M-Layer Proposal for Quantity Kinds & Units

Remove all ambiguity and generalize to all measurement scenarios.

- Explicitly augment the usual quanity value $q\ [Q]$ with the quantity kind (aspect) $q\ [Q]\ \langle Q \rangle$.
- Handle all scales: ratio, interval, cyclic, logarithmic, ordinal, nominal, . . .
- Handle any unit system.
- Uniquely identify aspects, scales and units in FAIR registries.

Section 3

Measurands and the MII Taxonomy

Measurands

- The quantity intended for measurement (radius or diameter?)
- Laboratories require accreditation for competency in specific measurement classes.
- The measurement classes should have unambiguous meaning and correspond to instrument functions (calibration requirements) and calibration results.
- Problems for machines:
  - The KCDB and accreditation statements present CMCs in a variety of ad hoc and unharmonized classification schemes.
  - Free-form text descriptions do not suffice.
  - Current descriptions correlate neither between document types nor organizations.

Example: Flow-Rate Descriptions in Use

Names from recognized bodies:

- KCDB: “fluid flow” (with “gas flow” or “liquid flow” and species)
- *ISO-IEC 80000*: “mass flow rate” and “volume flow rate”
- NVLAP: “[20/M05] Flow Rate”, plus “liquid flow” and “gas flow”
- DAkkS: ‘Gas flow rate”, “Volume of flowing gases”, and “Mass of flowing gases”

Neither names nor quantities consistent!

Example: Flow-Rate Descriptions in Use

Looking at approved SoAs from various ABs and Laboratories, we additionally find

> *"Mass Flow", "Liquid Flow", "Gas Flow", "Flow - Air", "Flow - Gas", "Flow - Liquid", "Flow - Gas (Air)", "Air/Nitrogen Flow", "Flow Rate by Volume", "Air Volume Flow", "Flow Hydraulic", "Fuel Flow", "Flow Rate by Volume for Compressible Gas", "Volumetric Flow Rate (Water)", "Liquid Flow Rate Inline", "Liquid Flow Rate Non-Intrusive", "Gas Flow - Leak", "Gas Leak", "Gas Flow Rate Into Vacuum", "mole-flow-rate", "Flow Meter Factor", "Flow Calibration Factor", "Flow Meter", "Determination of Flow Meter" (by gas or liquid species), "Electrical Output of Flow & Pressure Devices",*

and many other categorizations by flow instrumentation.

Further confusion: melt-flow index, flow velocity, air velocity, evaporation, load rate. Wow!

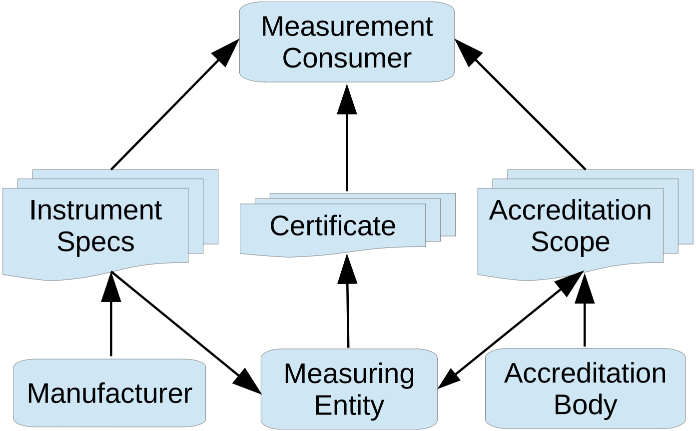
MII Proposal for Measurands

1. Standardize a taxonomy of measurands.
2. Link taxons to KCDB entry IDs and NMI service codes.
3. Tag digital document data with the taxons as metadata.

Spec: `Source.Voltage.DC`

SoA: `Measure.Voltage.DC`

Cert: `Source.Voltage.DC`



The MII Taxonomy and the M-Layer

Taxons associate to the aspect ID that governs the quantity values.

Quantity Value		Aspect ID		Taxon
				`Length.Circumference`
				`Length.Diameter`
				`Length.Form.Flatness`
1 ft				`Length.Form.Parallelism`
12 in				`Length.Form.Perpendicularity`
0.3048 m	$\Leftrightarrow$	$\langle$length$\rangle$	$\Leftrightarrow$	`Length.Form.Roughness`
30.48 cm				`Length.Form.Roundness`
304.8 mm				`Length.Form.Sphericity`
				`Length.Form.Straightness.Axis`
				`Length.Form.Straightness.Surface`
				`Length.Radius`

Draft Taxons

Capacitance
Conductance
Conductivity
Current.AC
Current.AC.Noise.RMS
Current.AC.Sinewave
Current.AC.Sinewave.2Phase
Current.AC.Sinewave.3Phase
Current.AC.Squarewave
Current.AC.Trianglewave
Current.DC
Current.DC.Delta.Current.LoadEffect
Current.DC.Delta.Current.SourceEffect
Current.DC.OutputAndReadback
Density.Mass.Gas
Density.Mass.Liquid
Density.Mass.Solid
Energy.AC.Sinewave
Energy.AC.Sinewave.Simulated
Energy.AC.Sinewave.Simulated.2Phase
Energy.AC.Sinewave.Simulated.3Phase
Energy.DC
Energy.DC.Simulated
Force
Frequency
Frequency.AmplitudeModulation.Rate
Frequency.FrequencyModulation.Deviation
Frequency.FrequencyModulation.Rate
Frequency.PhaseModulation.Rate
Humidity.Absolute
Impedance
Inductance
Length
Length.Circumference
Length.Diameter
Length.Form.Flatness
Length.Form.Parallelism
Length.Form.Perpendicularity
Length.Form.Roughness
Length.Form.Roundness
Length.Form.Sphericity
Length.Form.Straightness.Axis
Length.Form.Straightness.Surface
Length.Radius
Mass.Apparent
Mass.Conventional
Mass.True
Phase.PhaseModulation
Phase.ReflectionFactor.RF
Phase.TransmissionFactor
PhaseNoise.SideBand
Power.AC.Sinewave
Power.AC.Sinewave.Simulated
Power.AC.Sinewave.Simulated.2Phase
Power.AC.Sinewave.Simulated.3Phase
Power.DC
Power.DC.Simulated
Power.RF.Sinewave
Pressure.Hydraulic.Static
Pressure.Pneumatic.Absolute.Static
Pressure.Pneumatic.Differential.Static
Pressure.Pneumatic.Gage.Static
Ratio.AmplitudeModulation
Ratio.AmplitudeModulation.Delta.Rate
Ratio.Density.Mass
Ratio.Distortion
Ratio.Distortion.AmplitudeModulation
Ratio.Distortion.FrequencyModulation
Ratio.Distortion.PhaseModulation
Ratio.DutyCycle
Ratio.FrequencyModulation.Delta.Rate
Ratio.Humidity.Relative
Ratio.Humidity.Specific
Ratio.PhaseModulation.Delta.Rate
Ratio.Power.ReflectionFactor.RF
Ratio.Power.RF.Sinewave.Delta.Frequency
Ratio.Power.RF.Sinewave.Delta.Power
Ratio.Power.RF.Sinewave.Harmonic
Ratio.Power.RF.Sinewave.Spur
Ratio.Power.TransmissionFactor
Ratio.PulseModulation.CWtoPulsedPower
Ratio.PulseModulation.OnOffPower
Ratio.Torque
Ratio.Voltage.AC.Ripple.OnDC

Draft Taxons

Ratio.Voltage.AC.Sinewave.Delta.Frequency
Ratio.Voltage.AC.Sinewave.Delta.Voltage
Resistance
Resistance.Insulation
Temperature
Temperature.Radiometric
Temperature.Simulated.PRT
Temperature.Simulated.RTD
Temperature.Simulated.Thermocouple
Time.Interval

Time.Period
Time.PulseWidth
Time.Transient
Time.Transition
Time.Transition.PulsedRF
Time.UTC
Torque
Torque.HydraulicPressure
Voltage.AC
Voltage.AC.NoisePeakToPeak
Voltage.AC.Ripple.OnDC

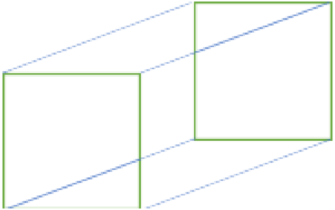
Voltage.AC.Sinewave
Voltage.AC.Sinewave.2Phase
Voltage.AC.Sinewave.3Phase
Voltage.AC.Squarewave
Voltage.AC.Trianglewave
Voltage.DC
Voltage.DC.Delta.Voltage.LoadEffect
Voltage.DC.Delta.Voltage.SourceEffect
Voltage.DC.OutputAndReadback
Voltage.DC.Segemented.Delta
Voltage.PeakToPeak

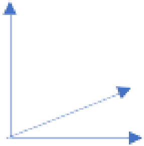
Section 4

More Advanced Semantics

Semantically Qualified Quantities

- Applies to machine-actionable operations
- May involve a more thorough quantity hierarchy
- Problems for machines:
    - No knowledge of quantity relations ($F = ma$)
    - No semantic knowledge (Which mass and acceleration?)
    - Consider a rectangular solid:
        - How do we define a perimeter, e.g., as a legal calculation?
        - Lengths on different axes (L_x, L_y, L_z) do not add linearly.
        - Falling back to the abstract length drops the perimeter ID. (Which face?)



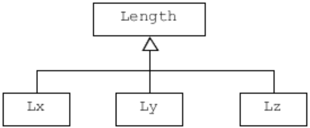


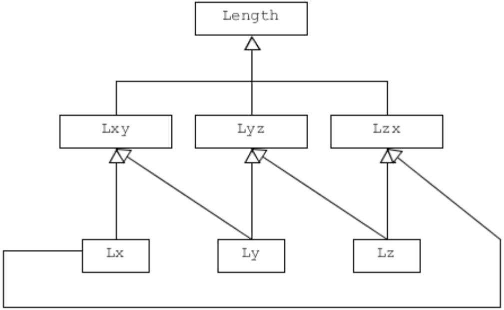
Extension Possibilities for Semantic Augmentation

Establish a hierarchical ontology of quantities to control calculations?

- `Length.Lxy.Lx`
- `Length.Lxy.Perimeter`
- Ontologies to distinguish shapes?

The NCSL International 141 MII and Automation Committee does not expect to build these; we merely offer ideas for thought.





Section 5

Conclusion

Incremental Steps toward Ideal Representations

1. M-Layer
   - Applies to all quantity values, including uncertainties
   - Unambiguous quantities to support any measurement software
   - Generalized scales & units for any measurement scenario
2. MII Measurand Taxonomy
   - Unique measurand IDs with unlimited human-readable aliases
   - Fully qualifies measurands for interoperable digital documents
   - (DCCs, instrument specs-DCRs, SoAs)
3. Semantic representations
   - Augmented representations for machine-actionable data
   - Future smart calculations, derivations

Collaboration

- Current information
  - Informal taxonomy at `https://www.metrology.net/home/metrology-taxonomy/`
  - Open-source taxonomy and SoA editors: `https://github.com/CalLabSolutions/Metrology.NET_Public`
  - Further info: http://miiknowledge.wikidot.com/
- Going forward
  - GitHub for configuration management: collaboration, submissions, approvals
  - M-Layer and MII Taxonomy specification and governance documents
  - `https://github.com/NCSLI-MII` opening for public participation soon
  - Prototype M-Layer registry and API now up and running

Acknowledgments

Please see the literature for further details.

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And Thank You for your time!

Collaboration opportunities? Please bring your expertise!

Questions?