An IoT Interface for Industrial Analog Sensor with IEEE 21451 Protocol

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***Abstract*—An Internet of Things (IOT) interface is introduced in this paper with the goal of filling the compatibility gap between currently available industrial analog sensors (legacy sensors) and network protocols. It is intended to be compatible with conventional analog sensor outputs with current loop, voltage and pulse outputs. Connection to the Internet is via Ethernet. To this end, IEEE 21451 family of standards is employed as a reference to come up with an interoperable interface. This family of standards provide an infrastructure which allows auto configuration (plug and play) and interoperability without the need for operator intervention. Transducer electronic data sheets (TEDS) play a key role in this process and they supply the system with the operating characteristics that are needed to use the transducer modules. The TEDS-only version of this family of standards (IEEE 21451-4) has received significant attention and is being used in this paper. The developed interface consists of transducer interface module (TIM) and network capable application processor (NCAP). Any type of industrial analog sensor can be connected to this interface and the interface will convert the input signal from analog to digital, format it in engineering units and then ref-format it in Internet format. The primary format of IEEE 21451-4 is XMPP which emphasizes on interoperability and security of messages in a network with machine to machine (M2M) communications that can be sensors, actuators and other type of devices.**

***Index Terms*— Analog sensors, Transducer Electronic Data Sheet (TEDS), Network Capable Application Processor (NCAP), Transducer Interface Module (TIM).**

I. INTRODUCTION

THE value of industrial digital sensors with network protocol for the Internet of Things has been widely recognized and they provide many benefits in the industrial environment [3,7,8]. The Industrial Internet of Things (IIoT) is the future for which sensors play a major role [6]. However, many high performance sensors are only available with analog outputs as of today. Lack of suitable network interfaces for commonly available industrial sensors with analog output or legacy sensors is sensed. Not only it is often impractical to replace existing (legacy) analog sensors-which work well and expected to last for many years-with digital ones, but many new industrial sensors with desirable features are only available with analog signal outputs. To address this problem, we have developed an easily implemented interface which converts analog sensor signals to digital with network compatible formats. The primary or default format is XMPP using the IEEE 21451-4 [1,4,9] protocol. Although other options are available, adding an Internet compatible interface to convert analog sensors is often the easiest and cost effective near/mid-term solution for IoT compatibility. We believe that the interface which combines hardware and software features needed for IoT will allow more extensive implementation of machine-to-machine operation.

Different elements of a system is divided into two general categories of devices by the IEEE 21451 family of standards: Network capable application processor (NCAP) and transducer interface module (TIM) [1]. NCAP is a processor based device and has the role of a gateway between the users' network and TIM [1]. It is possible to have different manufactures build the NCAPs and the TIMs but as long as both comply with this standard, they should be able to interoperate. The developed interface, in terms of IEEE 21451 terminology, is a TIM without the sensor element but with a network capable application processor NCAP. Together with the external sensor element with signal conditioner (e.g. pressure sensor), they are a combined TIM/NCAP.

II. INTERFACE GENERAL DESCRIPTION

The interface (Fig. 1) consists of analog signal inputs with several options (voltage, current, pulse, switch), an analog to digital (a/d) converter, a microcomputer, cache/TEDS memory and a digital communication section (Ethernet and other options).

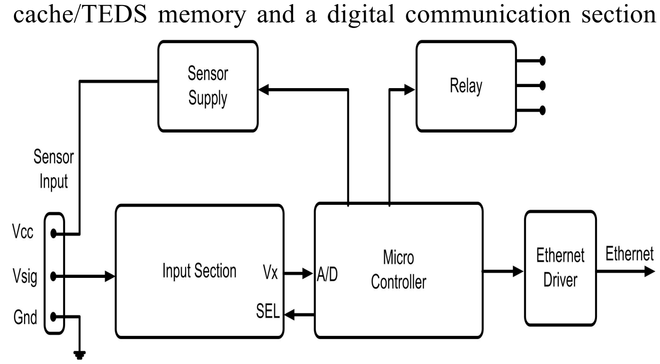

Fig. 1. Block Diagram of Interface

Analog data is converted to digital, formatted in engineering units, re-formatted to the proper Internet formats. The interface with external sensor functions as a combined TIM and NCAP. Sensor data, and also the TEDS data, is stored in a non-volatile (flash or EEPROM) memory so that it can be transferred immediately to the Internet upon request. Typically, the storage may be only for a few milliseconds (ms) but for some applications (data logging), the time scale may be much longer.

Although the IEEE 21451-1 standard has many options, we have chosen the XMPP (-4) over Ethernet as the primary or default protocol. Power for the unit is provided by POE (power over Ethernet) or by an external 5-volt supply.

III. Detailed Description

A. Analog Input Section

The input section has a number of options which match the signal output of most industrial analog signal sensors, specifically:

- ❖ Voltage:
  - Output from signal conditioner is proportional to voltage, most often 0 to 5v.
  - Popular with temperature and pressure sensors.
- ❖ Current:
  - Sensor transmitter output is current from 4 to 20 mA (4 mA is zero signal and 20 mA is full scale).
  - Popular with temperature and pressure sensors.
- ❖ Pulse:
  - Signal is proportional to the frequency of pulse or square wave output.
  - Popular with flow sensors.
- ❖ Switch: NPN/PNP or dry contact
  - Proximity sensors (inductive, capacitive, ultrasonic and photo) current output requiring load.
  - Dry contact (microswitchor magnetic reed)

The sensor signal input connector is 3-pin ($+V_{cc}$, V_{sig}, gnd). A multiplexer (Fig. 2) selects the input mode. A sensor supply voltage (3, 5, 12 v) is also selected.

When the 4-20 mA current loop mode is selected, an input of 4 mA corresponds to a zero sensor reading and 20 mA corresponds to full scale. The full scale reading (e.g. 15) and the units (e.g. PSI) are set via software by the user. The default setting is 100%.

When the 0-5v mode is selected, 5v corresponds to full scale. For the pulse input mode, 2 kHz corresponds to full scale. The switch input is binary (0 equals to off and 1 equals to on) intended for proximity sensors with either PNP or NPN load configuration [11] or dry contacts.

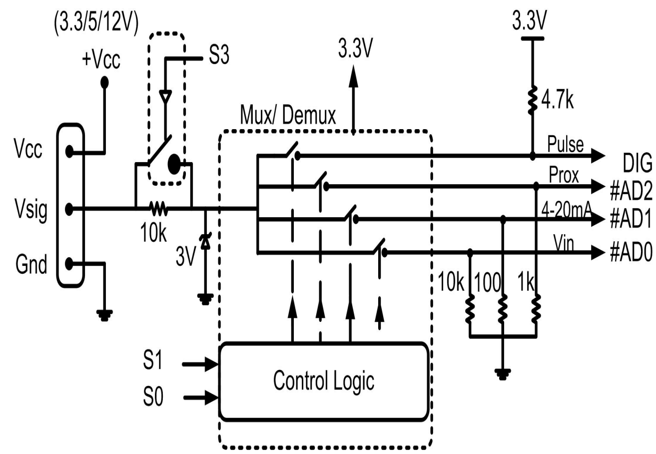

Fig. 2. Input Signal Section

The input multiplexer is configured during a setup period. The sensor supply voltage ($+V_{cc}$,) is also configured during setup. The configuration scrren is explained separately in the following.

B. Microcontroller

The analog signal from the analog input multiplexer i.e. read via the a/d input (12-bit) of the microcontroller.

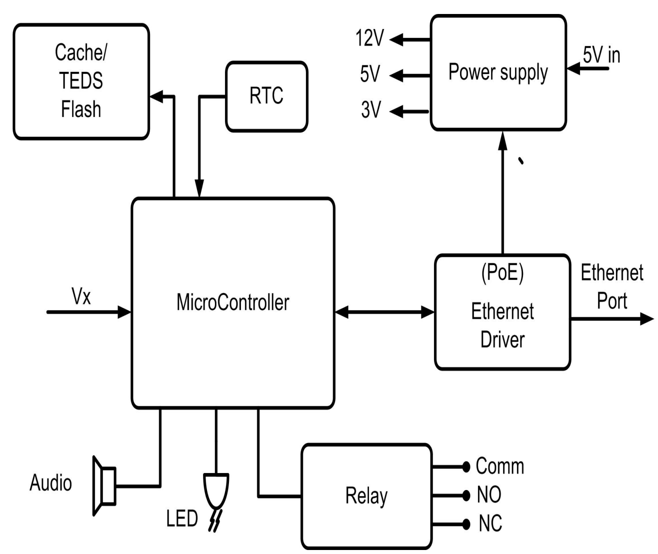

Fig. 3. Microcontroller and Ethernet Driver

Data is read periodically, at a selectable interval, converted to engineering units and stored in cache memory along with a time stamp. The data may be transmitted to the Internet immediately, upon request, or if a present threshold (event) is exceeded.

C. *Configuration Screen*

The screen used to configure the sensor is shown in Fig.4. The manufacturer may configure the interface for a particular sensor type (i.e. pressure) when sold and not make the screen available to the customer.

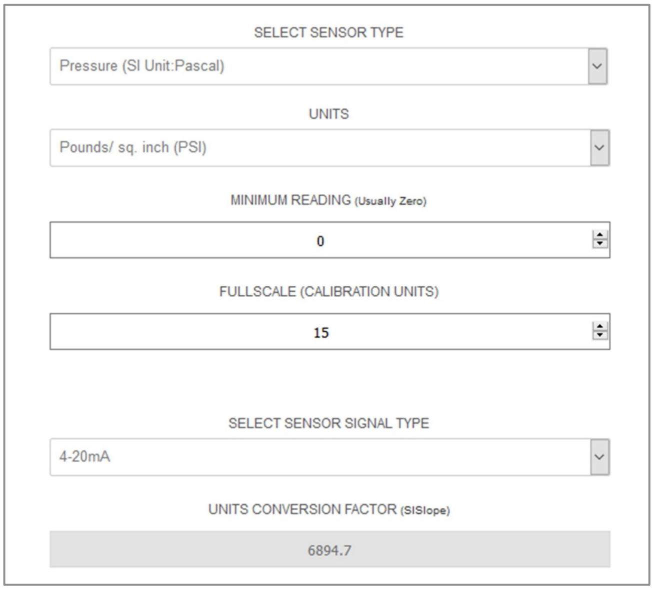

Fig. 4. Configuration Screen

D. *TEDS*

Several TEDS are defined in the IEEE 21451 standard; four of them are required (e.g. Meta-TEDS or PHY TEDS) and the remaining are optional (e.g. Calibration TEDS or Text-based TEDS) [1]. Table I lists all the defined TEDS in IEEE 21451 family and specifies if they are required or optional.

TABLE I
DEFINED TEDS IN IEEE 21451

TEDS	Necessity
Meta-TEDS	Required
TransducerChannel TEDS	Required
Calibration TEDS	Optional
Frequency Response TEDS	Optional
Transfer Function TEDS	Optional
Text-based TEDS	Optional
End User Application Specific TEDS	Optional
User's Transducer Name TEDS	Required
Manufacturer-defined TEDS	Optional
PHY TEDS	Required

The TEDS (Transducer Electronic Data Sheet) required by the IEC/ISO/IEEE 21451 standard is given in table III for a pressure sensor with timestamp. Three optional actuators are present for alerts and local data readout: audio/buzzer, LED indicator, and LCD 16x2 segment display.

E. *IEEE 21451 Data Format*

The sensor data (see TEDS) is transmitted in 32-bit floating point in SI units (as required by the standard). As an alternative the data in the calibration or preferred units are given in the associated CalTEDS.

TABLE II
META-TEDS EXAMPLE [1]

MSB LSB	FIELD DEF
00 00	TOTAL LENGTH
00 24	
03 04	HEADER
00 01	03 04 00 01 01 01
01 02	
04 0A	UUID
81 C0	04 0A 81 C0 F9 74 48 81 F5 62 2E 78
F9 74	
48 81	
F5 62	
2E 78	
0A 04	OPERATIONAL TIMEOUT
BF A0	0A 04 3F 00 00 00
00 00	
0D 02	NUMBER OF CHANNELS
00 01	0D 02 00 01
F8 D1	CHECKSUM

The primary format is XMPP [12] with the 21451 format. Optionally the data is available in HTTP, JASON, SNMP and other formats.

F. *Hardware*

The interface hardware implementation, outside the case, is shown in Fig. 5. Note the 3-pin sensor connector (also Ethernet and external power supply).

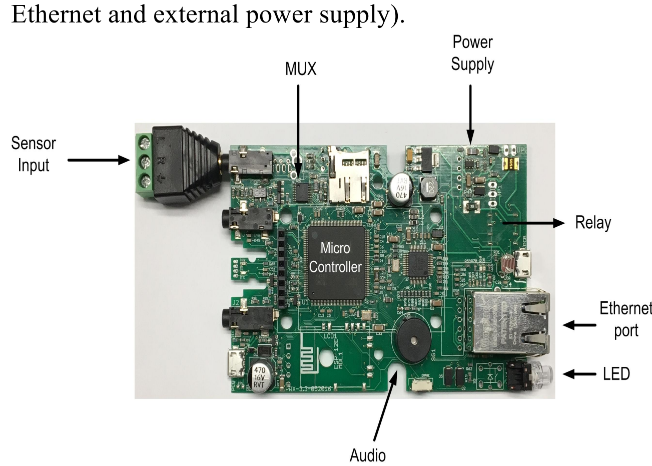

Fig. 5 Photo of Interface

TABLE II
TEDS Listing

#	Access code	TEDS Name	Chan	S/A[1]	TEDS fields[2]	Data type	# Bytes[3]
1	1	MetaTEDS	-		UUID [], Timeout[], # Channels	--	13
2	3	ChanTEDS	1-Time	S		TAI 64-bit integer	
3	5	CalTEDS	1-Time	S	Intercept(31)=17, SISlope[4]=1, Data(128), CalUniits(129)="sec"	UTC[5] 32 –bit int text	
4	3	ChanTEDS	2-pressure	S	CalKey[10], ChanType[11], PhyUnits[12], UnitType[50]	float 32-bit	
5	5	CalTEDS	2-pressure	S	SISlope[30], Data(128) CalUnits[129]	Float, text	12+
6	3	ChanTEDS	3-Audio	A	CalKey[10], ChanType[11], PhyUnits[12], UnitType[50]	8-bit integer	
7	3	ChanTEDS	4-LED	A	CalKey[10], ChanType[11], PhyUnits[12], UnitType[50]	8-bit integer	
8	3	ChanTEDS	5-LCD	A	CalKey[10], ChanType[11], PhyUnits[12], UnitType[50]	8-bit integer	
9	12	XdrNameTEDS	-		"IOT Interface"	text	
10	13	PhyTEDS	Serial, Dot 2		Type (10)=01 (internal)	--	2

[1] S=Sensor (read), A=Actuator (write)
[2] All have TEDS length and TEDSID (field3=access code) header (8-bytes) and Checksum (1's comp) footer (2 bytes)
[3] Number of data bytes, excluding header and footer (6 bytes)
[4] Multiply data in calibration units by SISlope to obtain data in SI units
[5] UTC (universal time code) in units of seconds since 1970, is, standard for Internet time and may be converted to YYYY-MM-DDT:hh:mm:ss+Z format for display[5]

IV. Conclusion

While sensors are inseparable components of the future of industrial internet of things (IIoT), it should be taken into account that much industrial equipment is equipped with legacy sensors which work well and are expected to last for many years. Considering the current situation, adding an internet compatible interface to convert analog sensors is often the easiest and cost effective near/mid-term solution for IIoT compatibility. Therefore, in this paper an Internet of Things (IoT) interface was proposed which is based on IEEE 21451 protocol. Many types of sensors with different types of channels can be connected to this interface which is a combined TIM/NCAP.

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