Current Status of the IEEE 1451 Standard-Based Sensor Applications

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***Abstract*— In this paper, we have discussed the sensor-based applications and what is necessary for the dissimilarities in hardware realization and algorithm. This paper presents the existing state-of-the-art of IEEE 1451 standard-based sensor applications and is mainly focused on standard transducer interface module (STIM), network capable application processor (NCAP), and transducer-independent interface (TII). They have some major factors that are regularly imperative in the development of IEEE 1451 standard-based applications, such as plug and play facility, for one or more than one STIM, communication protocols/network's, architecture, reliability, maintenance, accuracy, easy to use, cost, transducer electronic data sheet, test facility, and so on. The above concerns are also summarized by reference to research articles on STIM, NCAP, and TII. Highlighting is on the predictability of dynamic applications that concentrate on the above mentioned criteria.**

***Index Terms*— IEEE 1451, wireless standard transducer interface module (WSTIM), transducer independent interface (TII), network capable application processor (NCAP).**

I. Introduction

OVER the past quarter century, sensors are used universally, such as industrial automation, smart building, aerospace, household appliances, health care, automotive, manufacturing, process control, green vehicle, homeland security, monitoring of greenhouse gases, etc [1]–[4]. Basically, a sensor is a device that detects a physical, chemical and biological quantity and converts to the electrical signal. The raw sensor analog signals convert into the digital output or usable form through the microcontroller, signal processing with amplification circuit than the sensor work as an intelligent sensor or smart sensor [5]. The functionality of the smart sensor is simplifying the integration of the transducer into applications [6]–[8]. The IEEE 1451 standard based intelligent systems have many advantages such as real-time monitoring, controlling, plug and play facility, easy interface to server based application, etc. Researchers have been explained the IEEE 1451 based environment monitoring systems.

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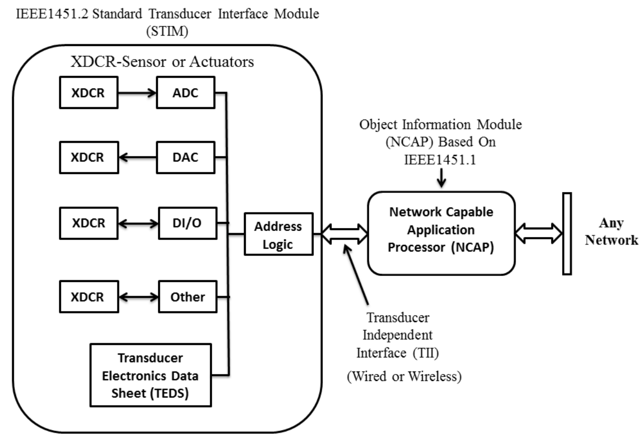

Fig. 1. IEEE1451 based application conceptual diagram [1]–[7].

The environment monitoring system automatically measures and records the real time parameters in the environment. The IEEE 1451 standard based intelligent system is consists of standard transducer interface module (STIM), transducer independent interface (TII), and network capable application processor NCAP (GUI PC).

The STIM, NCAP, and TII based applications in the different area such as environment monitoring, elderly health carrying, control of the smart building parameter, household appliances, processes control and factory automation, green vehicle, rockets intelligent testing, waste water treatment, etc were reported in [9]–[32]. Researchers define the intelligent system; basically, intelligent system is consisting of data acquisition unit, memory card work as a transducer electronic data sheet, display unit, and interface facility to the network [23]. The IEEE 1451 standard based conceptual diagram is shown in Fig. 1.

This article presents an overview of the existing state-of-the-art practices for IEEE 1451 standard based sensor applications and is mainly focused on standard transducer interface module, transducer independent interface and network capable application processor.

II. Standard Transducer Interface Module (STIM)

In this section we have explained the state of the art of the STI (standard transducer interface) module in diverse area such as environment monitoring and control, in-situ greenhouse

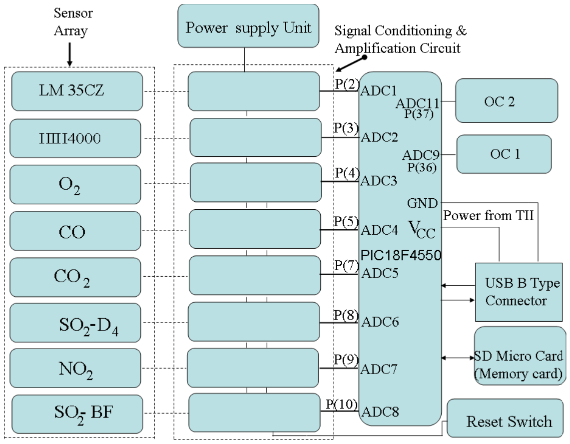

Fig. 2. Block diagram of the IEEE1451.2 based standard transducer interface module [30].

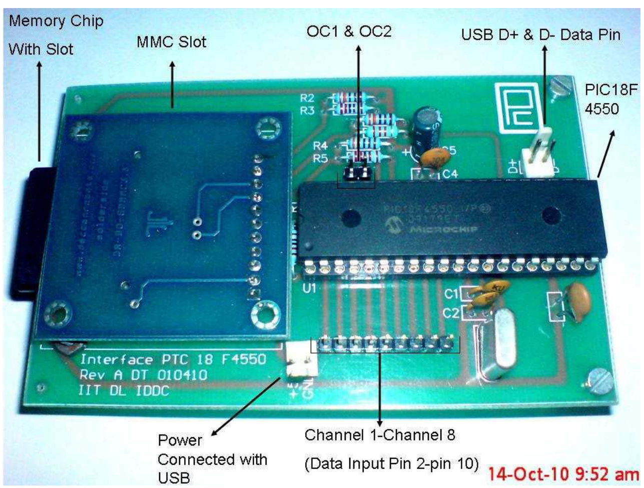

Fig. 3. Photograph of the IEEE1451.2 based STIM [30].

monitoring, volatile organic compound measurement through cognitive approach, factory automation, smart building, green vehicle, machine condition monitoring, robotics, medical, etc. The basic diagram and photograph of the IEEE 1451.2 standard based developed STI module by researchers is shown in Figs. 2 and 3, respectively.

The IEEE 1451.2 standard based STIM that contains the sensor array with signal conditioning circuit, communication capability, and transducer electronic data sheets (TEDS) [5]. The IEEE 1451.1 standard based NCAP (network capable application processor) object oriented model, IEEE 1451.2 standard based STIM (standard transducer interface module), IEEE 1451.5 standard based TII (transducer independent interface) module, STIM module interface with web server, and ethernet, plug and play facility in the STIM module, wireless standard transducer interface module, wireless network capable application processor, RS232 communication protocol, RS485 protocol, zigbee communication between WSTIM (wireless standard transducer interface module) and WNCAP (wireless network capable application processor), transducer electronic data sheet in the STIM module, radio frequency identification data tag, remote monitoring through OGC-SOS, MIMOSA/OSA-CBM were reported in [1]–[12].

Dunbar proposed plug and play sensors in the wireless network. They used the 40 MHz, 900 MHz, and 2.4 GHz frequencies in the system development [13]. Licht proposed a mix mode interface and transducer electronics data sheet in the transducer [14]. Eccles explained the need of standard transducer interface module in aerospace testing [15]. Rossi *et al.* proposed open and standardized resources for the smart transducer interface module. They constructed, IEEE 1451 standard based network node through python programming and java languages, low cost programmable logic devices, linux, ethernet architecture, and personal computer resources. The construct node is used in the server communication model for clients. The low cost standardized technology is used for network control and other advantage in the Ethernet based application for collision detection [16].

Sveda *et al.* proposed the IEEE 1451.2 standard based integrated sensor network framework via virtual interface architecture (VIA). They discussed the procedure of real time pressure measurement technique [17]. Lee *et al.* design IEEE 1451 based STIM module for an in-vehicle networking (IVN). They designed a Controller Area Network (CAN) based STIM and NCAP for motor speed control [18]. Schmalzel *et al.* developed a prototype intelligent rockets test facility. The IEEE 1451 based smart sensor components play key role in on condition that the distributed intelligent system to carry out analysis of overall health. They contribute the chain of command of the health fortitude at the system level [19]. Cummins *et al.* presented IEEE 1451 standard based single chip of the standard transducer interface module. And they also explained the ADC (analog to digital convertor) calibration process [20]. Batista *et al.* proposed IEEE 1451 standard based multi interface module (I2M) for automation of industrial processes. Process automation with I2M is communicated through either wires or wireless communication. They used the FPGA with NIOS II processor, zigbee communication based on IEEE 802.15.4 standard, and as well as RS232 standard [21]. Song *et al.* proposed a prototype IEEE 1451 standard based service-oriented sensor (SOS) data interpretability architecture for open geo-spatial. And they also explained the web services smart transducer web services (STWS) [22]. Kularatna *et al.* developed a low cost environmental air pollution monitoring system based on IEEE 1451.2 standard. This system measures concentration of gases such as SO_2, NO_2, CO, and O_3. The power consumption and response time of the Ozone gas sensing module is approximately 1 W and 1 minute respectively. They implemented a smart transducer interface module (STIM) using analog device AD_UC 812 microconverter. Visual Basic 6.0 based GUI PC is developed and the communication between STIM and NCAP through PC parallel port [23].

Sarry *et al.* developed a semiconductor sensor array based gas discriminator system for the measurement of carbon dioxide, forane products [24]. Ramos *et al.* proposed a LabVIEW based virtual instrument for suitable of testing of NCAP and STIM module [25]. Grimaldi *et al.* presented a LabVIEW and object oriented based techniques for suitable

TABLE I

ARCHITECTURE OF STANDARD TRANSDUCER INTERFACE MODULES

Refer.	Application	Architecture	Transducer Electronic Data Sheet (TEDS) Architecture	Programming Environment
1-7	Machine condition monitoring	Centralized controller (PLC system)	Web browser based DMC control	C
16	General purpose	FPGA	TEDS ROM	VHDL
17	Pressure measurement	8052, and Rabbit	Microcontroller memory	C
18	Intelligent vehicles	PIC 16F877	256-B EEPROM	Embedded C
19	Rocket intelligent testing module	---	Microcontroller	MATLAB
20	Transducer interface chip	8052	External memory	….
21	Automation of industrial process	FPGA	Processor memory	X-CTU
22	VOC monitoring	….	……	Web services
23	Air pollution monitoring	ADuC812	chip flash data memory (640bytes)	C++
24, 25	Gas discrimination in air-conditioned, & virtual instruments testing	PIC12F877	Microcontroller memory	C++
28	Gas measurement	PIC16F873A	Microcontroller memory	C
29	sensor selection in pattern recognition	AduC812 & Z86E08	External memory (1-512 MB flash and 2-512 MB SRAM)	C
30, 31, 32	Greenhouse gases monitoring	PIC18F4550,	Micro SD card (MMC)	Embedded C
34, 35	Environment monitoring	RISC MPU (8bit)	Flash ROM 32kbyte, & internal SRAM 1kbyte	…
37	Environment monitoring	18F8520	EEPROM & MMC	C
38	General purpose	AT89C51	Microcontroller memory (Same operating frequency)	C
39, 40	32 analog channel	8052	(i) 640 bytes Flash for data, & 8K bytes flash ROM for program, (ii) External expansion memory 16 M bytes	Delphi (PC software)
41	Solar radiation & environment monitoring	ST62E20	24C65EEPROM	C++
42	House environment	8051, PDA	PC Memory	VHSIC hardware description language (VHDL)
43	Explosive gas recognition	TMS320C31	DSP board memory	Embedded C
44	Recognition of volatile organic compounds	TMS320C31	DSP board memory	Embedded C
45	Hand held electronic nose (H^2EN	PIC 16C73A	Controller memory	Visual basic and EPOCC++
46	Electronic nose	MC68HC705C8A	EEPROM 2k*B	FPGA
47		SAB-C515C (8051/C501)	XRAM	….
48	Industrial purpose	ALTERA	Processor memory implemented through C/C++	C++, Java
50	Waste water treatment	……	Processor memory	C++
51	Condition monitoring in home	WRT54 gateway	…	C
52	Wearable physiological parameters	C8051F020	MySQL data base in the computer	C
53	Power management in smart buildings	…….	MySQL data base in the computer	C
54	Elderly carrying in a smart home	…..	……	C
56	Ocean observing systems	……	Microprocessor	MBARI PUCK
58	RFID sensor Tag	DW8051	EEPROM microprocessor	18000-6C
63	General purpose	MC9S08DZ128, LMX9838	…….	
65, 75	Thermal monitor in building	16 bit processor	Microprocessor	Embedded C
76	Animal health monitoring	Pic18F4550, and T56H	PC memory	Embedded C

of distributed measurement [26]. Ulivieri *et al.* presented IEEE 1451.4 standard based plug-and-play facility in the gas sensor array [27]. Pardo *et al.* developed a gas measurement system based on IEEE 1451.2 standard. This prototype system includes: four tin oxide gas sensors, one temperature sensor, one humidity sensor, and two digital actuators (valve and pump). They developed a module consisting of two blocks, namely, a signal conditioning circuit and a control module. The control module drives the actuators, acquires the sensor signal, and implements TEDS (transducer electronic data sheet) and the TII (transducer independent interface) interface [28].

Pardo *et al.* developed a gas sensor array based monitoring system which also included a temperature and a humidity sensor. The sensor array was connected to a data acquisition system through corresponding conditioning circuits.

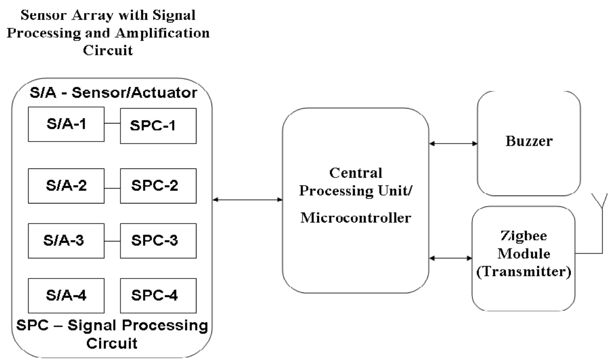

Fig. 4. Block diagram of STIM based on IEEE 1451.2 and IEEE 802.15.4 standards [9], [31].

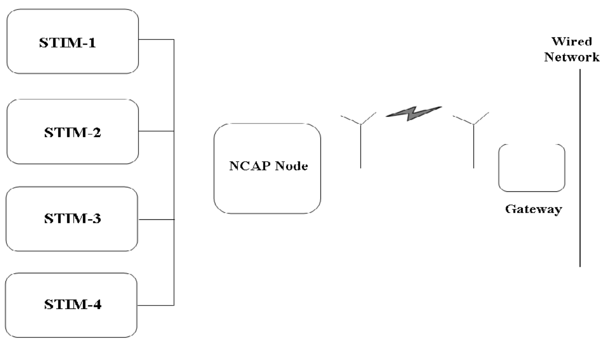

Fig. 5. Block diagram of wireless NCAP node [9], [10], [57].

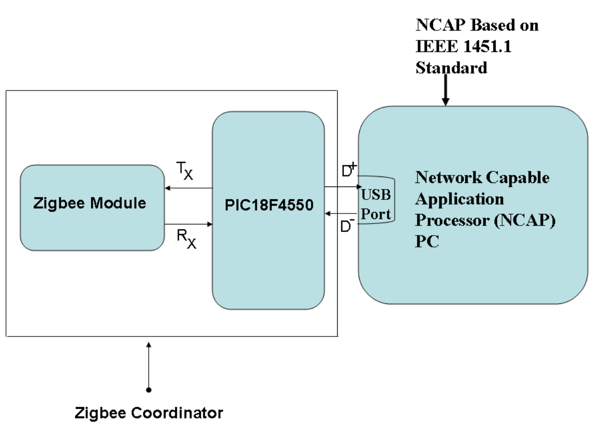

Fig. 6. Block diagram of WNCAP node [32].

A processor (microcontroller and digital signal processor) controls the measurement sequence and processes the measured data continuously [29]. Kumar *et al.* developed a low cost, energy efficient, plug and play environment monitoring system based on IEEE 1451.2 standard for indoor air quality gases and environmental parameter such as CO, CO_2, SO_2, NO_2, O_2, temperature, and relative humidity [30], [31] and they also used the IEEE 802.15.4 standard based zigbee communication. The IEEE 1451.2 and IEEE 802.15.4 standards based wireless STIM is shown in Fig. 4. [32].

Zhou *et al.* reported that low cost and high reliability serial bus sensor network for intelligent sensor system.

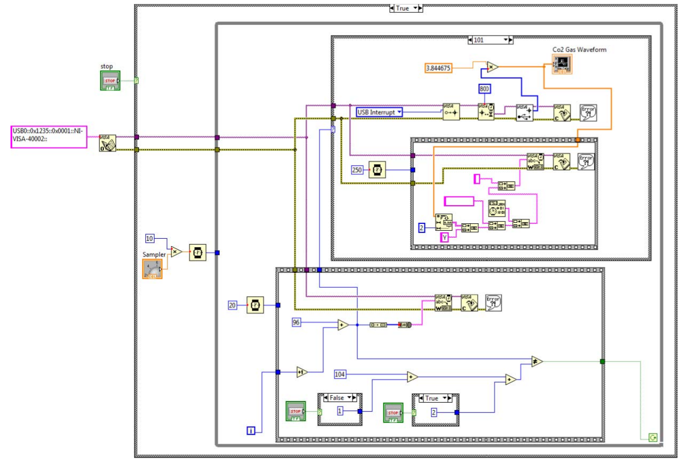

Fig. 7. LabVIEW-based block diagram of the NCAP module [30].

Several existing serial buses, I^2C (integrated circuit commonly referred to as "two wire interface"), and SPI (serial peripheral interface), TII (transducer independent interface) have been reviewed for different applications [33]. Bissi *et al.* described the structure of IEEE 1451 standards multiprocessor control system and they also explained the RS232 asynchronous communication between STIM and NCAP [34], [35].

Woods et al. presented a technical overview on the IEEE 1451.2 standard based STIM (standard transducer interface module) with TEDS (transducer electronic data sheet). Key technical features have been discussed such as representation of physical units, TEDS, triggering of sensors and actuators, calibration model, variable transfer rate, and support for multivariable transducers are briefly discussed, and plug-and-play operation are also given in [36]. Abas *et al.* developed a data management system for environment monitoring. The system divided into two parts such as data logger and graphic user interface (GUI). Data logger is capable to save captured data in MMC in real time of the environmental parameter such as temperature, humidity, and irradiance [37]. Camara *et al.* present a design of IEEE 1451 standard based STI module. The system is capable to work with many different transducers without changing the hardware and software [39], [40]. Mukaro *et al. d*eveloped a low cost microcontroller based data acquisition system for solar radiation and environment monitoring [41]. Sung *et al.* presented a PDA (personal digital assistant) based wireless sensor module for air quality monitoring such as humidity, temperature, dust, and CO_2 [42]. Lee *et al.* developed a TMS320C31 based explosive gas recognition system with semiconductor sensor array [43], [44]. Chueh and Gardner *et al.* designed a prototype real time data acquisition system for chemical composition [45], [46]. Batista *et al.* proposed a hardware and software transducer network based on IEEE 1451 platform. The NIOS II processor resources on *Alteras Cyclone* II FPGA are used in the development of the hardware and C/C++ is used in the software development [48]. Kelly *et al.* developed an internet things and zigbee based environment condition monitoring system for homes. They proposed the procedure of real time monitor light intensity and power [51]. Malhi *et al.* developed a

TABLE II

ARCHITECTURE OF NETWORK CAPABLE APPLICATION PROCESSOR MODULES

Refer.	Application	GUI Programming	Monitoring Parameter	Display Output Digital/Analog
1	Machine condition monitoring	Java web browser	Drain, heater, temperature, valve	Java Applet
7	Machinery information management system	MIMOSA /OSA-CBM, web-based/XML, CORBA-IDL/Java	General	….
16	General purpose	Java, internet client	General	….
17	Pressure measurement	Java		Java Applet, TCP/IP ethernet
18	Intelligent vehicles	MC68HC912D60	Motor, encoder, monitor	….
22	VOC monitoring	HHTP/SOAP (internet)		SOS services sensor data
23	Air pollution monitoring	Visual Basic 6.0	CO, NO_2, SO_2, O_3	Digital outputs
24	Gas discrimination in air-conditioned	LabVIEW 6.1	Two any analog sensor	Digital outputs
27, 35	Gas sensing module	LabVIEW 4 channel, N- module	4 channel	Digital output
28	Gas measurement systems	……	4 gas sensors, Temp, RH, 2 digital actuators	…..
30	Greenhouse gases	LabVIEW 9.0	CO, CO_2, SO_2, NO_2, O_2,, T, RH	Digital and graphical waveform
37	Environment monitoring	C#, JAVA, & OSS Rython, C/C++, finally best result obtained with JAVA	Humidity, temperature, irradiance	Waveform
38	General purpose	**C**	……	LCD display
48	Pressure monitoring	SCADA	Pressure	Graphical
49	Rocket engine testing	C++	Temp, pressure, O_2	Graphical
50	Waste water treatment	UML-ACE/C++	Pump, valve, mixer, control	ACE Block
51	Condition monitoring in home	C# and web interface using PHP and Java	Hot water system, electrical appliances, measurement environment temperature	Graphical waveform
52	Wearable physiological parameters	C#	Temp., heart rate, impact sensor	Graphical waveform
53	Power management in smart buildings	C# and web interface using PHP and Java	Voltage and current	Graphical waveform
54	Elderly carrying in smart home	….	Voltage and current	….
63	General purpose	ALIX3C3	Temp, humidity	TCP/IP
64	Open measurement and control system	.NET frame	….	XML and web services
62	Thermal monitor	Visual C++ and Java	Temp., RH	Web form and digital

physiological parameter monitoring system and they proposed the procedure of real time monitor of the temperature, heart rate, and impact. The proposed system is help for elderly carrying person [52]. Suryadevara *et al.* developed a real time smart monitoring and controlling system for household electrical appliances and the system is helpful for the save of electricity expense of consumers [53], [54]. Bermudez *et al.* explained the IEEE 1451 based SOS-OGC (open Geospatial consortium-sensor observation services) ocean observing application [56]. Seng *et al.* explained the IEEE 1451.0 and IEEE 1451.5 standards based wireless standard transducer interface module (WSTIM) [57]. Han *et al.* proposed IEEE 1451.7 standard based RFID (radio frequency identification) sensor and they achieved the power consumption of the baseband is approximately 18μW (clock frequency at 1.28MHz and Power supply at 1.2V [58]. Tseng *et al.* IEEE 1451 standard based internet of things framework based standard transducer interface series [59]. Guevara *et al.* proposed a wireless sensor network for control road traffic and also used the CAN (controller area network) network [60]. Depari *et al.* developed a VHDL based standard transducer interface module in a single chip [61]. Karatzas *et al.* developed generic intelligent sensor software architecture based on IEEE 1451 and SEVA BS-7986 standards [62]. Nieves *et al.* developed a universal plug and play device and also proposed the IEEE 1451 homogenize remote management and interoperability in transducer networks. They used the temperature and humidity sensor networks in the testing laboratory [63]. Wang *et al.* developed IEEE 1451. 2 standards based thermal monitor system [65]. Manders *et al.* developed IEEE 1451 based fault detection system for test bed for distributed and measurement control [66]. Table I represents the architecture of IEEE 1451 based standard transducer interface module (STIM) adopted by researchers.

III. NETWORK CAPABLE APPLICATION PROCESSOR (NCAP)

Network capable application processor is a logic components and it's can be divided into two groups, that is to say; support and application. The components of sustain are the network interface, and the operating

TABLE III
ARCHITECTURE OF TRANSDUCER INDEPENDENT INTERFACE MODULES

Refer.	TII	Standard	Communication Driver
1	Ethernet	IEEE802.1	NIST techniques
10, 11	Zigbee, WiFi, Bluetooth, 6 LowPAN	IEEE 1451.5	....
14	Mix mode interface	IEEE P1451.4	….
16,17, 23, 24, 28	Serial communication	IEEE 1451.2	C++
22, 24, 37, 38	RS232	IEEE 1451	C
18, 47, 60	CAN	IEEE 1451	…..
20	Parallel port SC	IEEE 1451.2	….
30	USB interface	IEEE 1451.7	VISA
32	Zigbee communication	IEEE 802.15.4	VISA
37	RS232	---	JAVA
38, 67	RS232	IEEE 1451	C
39, 40	Parallel port interface	IEEE1451	PC software tool in Delphi
41	MAX232 (Serial communication)	----	C++
42, 68	RS232	IEEE 1451	VHDL, C++
51, 52, 53, 54	Zigbee communication	IEEE 802.15.4	X-CTU
58	RFID	IEEE 1451.7	…..
65	RS485, radio, infrared, RS232	IEEE 1451.2	C
69	Internet	IEEE 1451.2	C
75	SIM20	IEEE1451	C
76	Zigbee communication	IEEE802.15.4	C

system. The details of the transducer interface hardware realization with a programming model and the operating system was reported in [1]–[9]. Figs. 5 and 6 represent the block diagram of the wireless network capable application processor developed by researchers. The IEEE 1451.2 standard based network cpable application processor; network capable application processor with IEEE 1451.4 mixed mode interface; IEEE 1451.5 standard based zigbee with 6LowPAN, WiFi, and Bluetooth was reported in [1]–[14]. Kularanta *et al.* developed a graphical user interface based on visual VASIC 6.0 language. The graphical user interface are display the status of the STIM, and measured air quality parameters [23]. Kumar *et al.* developed a LabVIEW based graphical user interface. The developed NCAP (network capable application processor) is supported eight channel STIM (standard transducer interface module). The GUI (graphical user interface) display of STIM information, monitoring parameter in digital and graphical waveform, and status of the micro SD card. The NCAP GUI is used for sample in the range of 1-100sec. The proposed LabVIEW based block diagram of the NCAP module is shown in Fig. 7 [30]–[32]. Abas *et al.* discussed the issues of the C++, Java, C# and Python based GUI (graphical user interface). Python based GUI is found to be easy to implement [37]. Kochan *et al.* proposed a low-cost reprogram capability NCAP is based on MCS51 device. The microcontroller runs in working mode and additional mode. The working mode is an interaction with high and low level networks; and the additional mode is a transferring the data and saving the operating program in the memory of the microcontroller [38]. Batista *et al.* presented a SCADA based NCAP. The proposed GUI display the output of the sensor in graphical waveform [48]. Gumudavelli *et al.* the proposed NCAP is supported host embedded intelligent processor information and display in digital waveform [49]. Lee *et al.* presented unified modelling language (UML) and ACE (automated comercial environment) mild ware based NCAP [50]. Malhi *et al.* presented a C# based graphical user interface (GUI). The GUI is suitable for display the output of the one or more than one sensors [52]. Viegas *et al.* presented NCAP module based on .NET framework for tiny client. The NCAP display the low and high threshlod value of the sensor and also display the sensor output in graphical waveform [55], [64]. Depari *et al.* presented a simulater based NCAP [61]. Table II represents the architecture of the network capable application processor module adopted by researchers.

IV. TRANSDUCER INDEPENDENT INTERFACE MODULE

Many researchers have been defined the transducer independent interface between STIM (standard transducer interface module) and NCAP (network capable application processor). One side of TII (transducer independent interface) is interfaced to the STIM and the other side is interfaced to the NCAP PC.

A parallel port interface between the STIM and the NCAP based on the IEEE 1451.2 standard and discussed serial data transfer was reported in [16] and [23]–[25]. Table III represents the architecture of the transducer independent interface reported by various researchers. CAN (controller area network) network is especially for automotive applications such as maritime, aerospace, medical equipment and industrial automation. Basically, CAN is a multi master broadcast serial bus standard. The sensor or actuators devices are not connected directly to the bus, but required a host processor and CAN controller. CAN network between STIM and NCAP for motor speed control was reported in [18] and [47].

A USB 2.0 interface between the STIM and the NCAP PC was reported in [30]. The USB based interface is so many advantages such as no extra power supply required on the STI module (USB 2.0 power range 500mA at 5.0 volt), the data transfer rate may be upto 480Mb/sec, hot pluggable, and automatic device detection.

Kumar et al. used the interrupt based data transfers. The virtual instruments software architecture (VISA) communication driver is used between the USB 2.0 and LabVIEW based NCAP GUI PC [30]. Kumar and Malhi *et al.* used the zigbee communication in the field of environment monitoring and biomedical application respectively. The XBee-PRO S2 module is used in the particular application through X-CTU [32], [52]. The transfer modes are based on the IEEE 1394 USB standard was reported in [70] and [71].

Alexander *et al.* presented a short rage communication for the vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). The V2V communications system is prevent the avoidable collisions by identifying unsafe conditions and warning of the driver. The IEEE 802.11p standard is used in the development of the system [72]. Toral *et al.* presents the current status of the intelligent transpiration system and also describes the field study method [73]. Vargas *et al.* developed the algorithm for vehicle detection in urban traffic scenes [74].

V. Conclusion

A review of the literature on IEEE 1451 based sensor applications were discussed and is focused only on STIM (standard transducer interface module), NCAP (network capable application processor) and TII (transducer independent interface) based applications. In the current version of the STIM is working under the control of NCAP. The NCAP program currently controls the STIM upto 1000kb/s fixed clock rate. This clock rate should be improved by receiving direct PC clock rates. However, if the STIM is improved with an LCD display unit and external memory (MMC/SDMC), it can be used as a portable instrument.

The STIM and NCAP can be further improved by developing a "wireless and GPS (global positioning system) link". In addition, the STIM, and NCAP will be explored in the area of green building, elder carrying, controlling of household appliances, harvesting power management, built environment monitoring, biomedical instrumentation, mine locomotive location system, train integrity system for train spotting, intelligent transportation, remote monitoring, VigilNet, smart agriculture farm, surveillance, etc. According to this investigation, the IEEE 1451 standards should be modified. And also add the signal interference problem in the modified standards.

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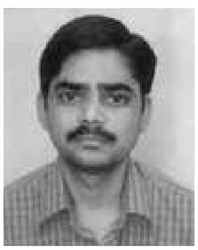

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