# IoT – An Intelligent Design and Implementation of Agent Based Versatile Sensor Data Acquisition and Control System for Industries and Buildings

Ashok Kumar Renganathan[#1], Nethaji Kochadai[#2], Sakthimurugan Chinnaramu[#3]

[#]*Sensors to Software, TCS Innovation Lab, TATA Consultancy Services Limited, Chennai, India - 603103*

***Abstract:*** *The objective of this paper is to address the major issues in small, medium and large-scale residential, industrial and commercial buildings in scenarios where Building Management solution is neither installed nor effective in monitoring and controlling the day-to-day energy spent& carbon footprint in buildings and industries. The need for Versatile Sensor Data Acquisition and Control System (VSDACS) with its design and features of the solution is proposed and discussed. Alternate to building management system implementation using available market products, VSDACS has unique provision to acquire sensors data irrespective of the Operational Technology (OT) protocols followed in the Internet Of Things (IoT) Edge and enables Edge control through EDGE Analytics. The key advantage of this solution is interoperability, since it runs smoothly in any Operating System and IoT Gateways with low hardware specification. VSDACS also addresses the multi-protocol in single loop especially in the case of data acquisition from Modbus RTU and BACnet MS/TP enabled sensors in single network. This single network setup on demand can be setup for other protocols with similar hardware interfaces for data acquisition. This paper discusses the VSDACS architecture advantages, performance evaluation of VSDACS with different IoT Gateways, OT Protocols and attractive experimental outcomes in detail. All the said features were experimented at Sensors to Software, TCS Innovation Laboratory, TATA Consultancy Services Limited, Chennai.*

**Keywords**: *building energy management solution, single loop multi-protocol support iot edge, vsdacs, iot data acquisition and control,iot edge protocols*

## I. INTRODUCTION

Efficient energy utilization in large residential, small to large scale industries and commercial buildings are of great importance to bring down the global energy demands thereby reducing the overall energy consumption to create environment friendly Eco-system. The resources used here is not limited to Electrical energy and it includes Water, Gas, Steam and Air. With increasing energy demand, raising energy costs, concern over climate change, focus on creating a sustainable and energy efficient economy is intensifying globally. Implementation of the Eco-friendly industries mutually helps the business stakeholders to save revenue in term of energy spent and significantly reduces the carbon footprint. One logical first step to save energy is through real time Energy monitoring system. While there are multiple vendors in market providing such solutions[4,5], there are inherent limitations including technical compatibility, level of customization, process orientation, most importantly implementation cost and so on. At present, Monitoring and Control of energy consumption is installed through Original Equipment Manufacturer (OEM) proprietary Building Management Solution (BMS) product [6,7], which involves installation of hardware equipment's at remote sites to monitor the energy consumption. The OEM's BMS solutions achieve high-level customization using the system control features. However, this monitoring system faces limitation when tries to optimize the energy demands for small buildings where there is scope for saving energy through process optimization, which is possible through low-level customization. Buildings with BMS installed collect data from sensors and shows the operational energy demand in a descriptive report if required. VSDACS in addition provides predictive and prescriptive analysis when combined with Energy Management Solution.

## II. MOTIVATION FOR VSDACS NEED

Commercial buildings significantly consume almost one third of total energy produced, which includes Retail Shops, Manufacturing Units, and Office Spaces etc. Due to rising energy costs reducing the energy consumption has become a priority for commercial buildings. So monitoring of energy consumption at such buildings and reduce the consumption at needless scenarios through effective analysis with available data is one major solution to this problem. Although, large commercial buildings are usually monitored for the consumption of energy especially electricity and water, generates descriptive report on demand basis. However, the small and medium scale commercial buildings not observed continuously for reduced usage of energy resources.

In such scenarios, an interface is required to connect with the sensors for data acquisition and performs the control operations based on feedback. The Authors can fulfil this interface demand by VSDACS with its versatile and robust design. Figure (1) shows the Overview of IoT enabled effective Energy Management System with VSDACS.The Energy measuring sensors/actuators installed in such buildings support industrial operational technology protocols such as BACnet, Modbus, OPC, CAN, Zigbee etc. Collection of data from the meters with such diverse protocols requires the use of either protocol converters (example: Converting Modbus RTU to Modbus TCP, Modbus RTU to ZIGBEE, BACNET MS/TP to BACNET IP etc.,) to covert or Software converter which could be handled through programming. Considering the case of energy management for organizations with buildings across multiple location, a cloud-based solution is required, hence a software architecture that could support many industrial protocols and either cloud based or cloud supported services is required to encourage the adoption of Energy Management Solutions in large businesses.

In market, IoT gateway devices with software interface for protocol support is available but limited to addressing specific/generic protocols such as Modbus, ZigBee etc.

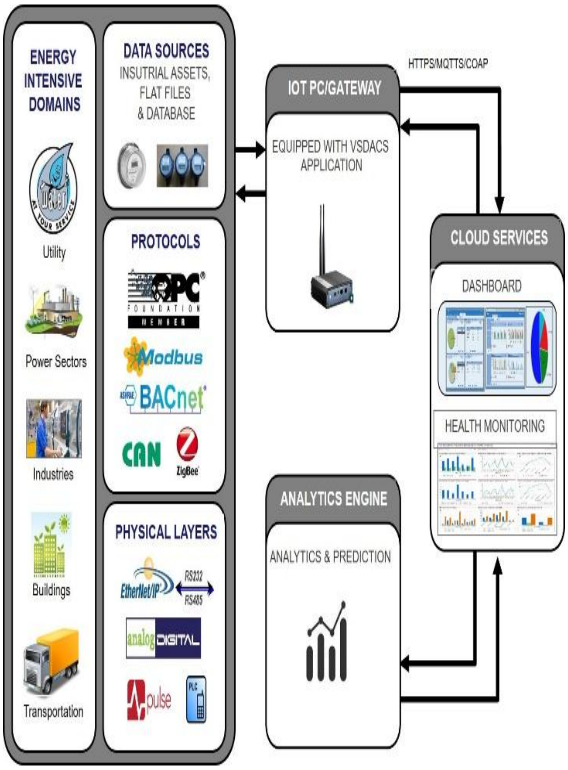


Fig.1 Overview of IoT enabled effective Industry/Building EMS using VSDACS

Such devices are not cost effective for implementation in large units. Given the diversity of IoT Gateways available designing a system that could work in devices with low specifications (less than 128 MB RAM) and scale to running multiple instances in larger 2GB ram devices would be desirable. Other constraint that comes in to play is that such devices might have only one RS485port thus limiting parallel operation of the data acquisition and control as well as limiting parallel operation of multiple protocols operating concurrently. There raises need to prevent errors occurring due to blocked ports. Voltron and BEMOSS [1], which focuses on software development using python, have addressed the design of IoT gateway software for complete implementation but without cloud services and effective control feedback to the systems. In addition, the work by Nugur et.al [2] sheds light on using python based tools to connect OT protocols to cloud based BEM services with web-sockets. The design in [2] involves running the entire IOT gateway software in a single device but in [1] and [10], the data acquisition and control part run in a separate device with the remaining parts of the IOT Gateway software run in a more powerful device. The various hardware platform supported by VSDACS listed in the table.1. The utility of python in IOT software development could not be under-mined because of the support for OT protocol libraries, availability of data analytics & machine learning tool kits and python developer friendly design paradigm.

**TABLE I**
**VSDACS SUPPORTED GATEWAYS**

| S.No | Device Model & Processor List |
|---|---|
| 1 | Lantronix SGX5150 Gateway - Single Core 400 MHz ARM9 32 bit 64 MB RAM (Custom Yocto Linux) |
| 2 | Asus Aaeon AIOT IGWS01 Gateway - Intel® Atom™ x5-Z8350 SoC 2GB RAM (Ubuntu 16.04.6 LTS) |
| 3 | Raspberry PI 3 Device - Quad Core 1.2GHz Broadcom BCM2837 64bit CPU 1GB RAM (Raspbian) |
| 4 | Lenovo Thinkpad T430 Device - Intel Core i7-3520M Processor CPU @ 2.9-GHz 4GB RAM (Ubuntu 14.04.6 LTS) |
| 5 | Lenovo Desktop Device - Intel Core i5-4570T Processor CPU @ 2.9-GHz 4GB RAM (Windows 7 32 bit) |

## III. VSDACS FEATURES

### *A. Multi-Language Programming Support*

Our approach in designing a unified IOT gateway interface VSDACS was to develop in python while providing the option to add the functionality to serial communication protocol packages in any language. This would provide developers the ease to communicate with the IoT gateway interface with protocols that does not have libraries in python.

### B. Easy To Configure & Scalable Solution

The design of the gateway interface should also make it possible to use multiple serial ports on the device when available. Providing a configurable interface to add meters and controllers would make connecting and managing new devices streamlined. Besides supporting cloud protocols such as MQTTS and HTTPS, it could be useful in connecting to IOT cloud services such as Amazon Web Services (AWS), Microsoft Azure, and TCS Connected Universe Platform (TCUP) etc. VSDACS helps small and medium scale enterprises to monitor, assess report, manage, and improve the energy saving opportunities effectively. This state of the art solution offers real-time data of energy Key Performance Indicators. It can also enable computing carbon footprint and compliance reporting requirement.

### C. Minimized Deployment Cycle

VSDACS can acquire data from different utility meters/actuators (Electrical Energy, Water, Gas, Steam, Air) involving various communications protocols and upload into the data warehouse/cloud archives hosted on any diversified data formats. VSDACS ensure seamless data flow from data sources (say Energy measuring meters/sensors) to Energy application/software for real time monitoring. This solution architecture have developed with intention to meet demand and supply side utility service providers, different consumers across industrial/commercial, residential sectors and integrating individual sites to the enterprise and considered various infrastructures incorporating Buildings, Plants and Houses. The Authors can customize, flexibly modify and deploy this solution with addressing specific requirements. The requirements vary based on site, geography, government regulations and type of utilities etc. VSDACS has been designed and developed to be configurable and readily deploy-able with minimum implementation cycle time, as all its components and functionality are fully tested for various aspects.

### D. Multi-Protocol Support

These features power the Versatile Sensor Data Acquisition and Control System (VSDACS) stands unique among the other available software interfaces. With VSDACS, users can successfully integrate multiple Operational Technology protocols in single gateway provided if necessary ports are available and the protocol list includes Modbus RTU, Modbus TCP/IP, OPC UA, OPC DA, BACnet IP, BACnet MSTP.

### E. Secured Data Transfer

In VSDACS, data transfer happens securely via encrypted packets. The Authors have used MQTTS, HTTPS protocol for secure data transfer. It will eliminate third party intrusion in the system.

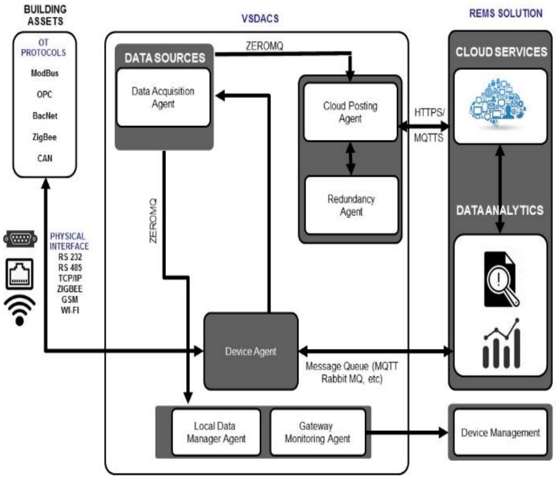


Fig.2 Versatile Sensor Data Acquisition and Control System (VSDACS) Architecture

## IV. VSDACS ARCHITECTURE & ALGORITHM FLOW EXPLANATION

VSDACS can be used to handle all Utility data, not limited to, Electrical energy but also Water, Gas, Air flow and Solar if installed that can be used to compute the Environmental impact due to Carbon foot print. VSDACS supports all the soft Gateway functionality, not limited to Real time data acquisition also Data Cleansing and Processing, Structured and/or non-structured data storage, Generation of alerts and warnings upon requirement, gateway monitoring and so on. In addition, authors coded and developed data cleansing and processing, data storage, error detection and correction, reporting and dash boarding for energy savings initiative etc., developed within TCS. VSDACS is a cost effective solution, which can cater to Home/Building/Factory Energy Management System implementation. In figure 2, The Authors show the Design of unified data acquisition and control management system. The Authors have classified the communication components of VSDACS into Device communication and Cloud communication, EDGE Analytics, Local Data Manager and Gateway Monitoring. (1) Device communication component contains agents Device Control Agent, Data Acquisition Agent and these components interacts with sensors and actuators (2) Cloud communication component includes Cloud Posting Agent, Cloud Network Failure Handler Agent. Figure 3 shows the flowchart of the VSDACS execution.

### A. Device Agent:

This Agent interacts with the assets connected to the system. It is the heart of the VSDACS system, which streamlines the request priority between asset control from cloud or edge analytics and data acquisition. Assets connected to the IOT gateway have controllable parameters, which is changeable remotely by writing/setting specific values through the IOT gateway. Respective serial communication protocol handlers are manageable in VSDACS for data acquisition from the meters and used for the writing values to the controllers. However, higher priority is available to control inputs over the data acquisition. The design of device agent made to facilitate the seamless control action on assets, which included temperature set point, lights luminescence, flow valves etc. The sensor control agent have made to work on a higher priority over the data acquisition agent in the cases where both agents use a common serial interface. The Authors need a well-designed sharing mechanism of the serial port to prevent the port blocking which might occur if the same serial port assessed by both the control agent and the data save agent. The Authors designed the device agent to wait and give priority to the control request. The asset control value is passing either from cloud server or from edge analytics agent. The cloud server can get the control value from either Customer User Interface or it can arise from the Data Analytics servers. The Authors forward the control request to VSDACS via MQTT. The MQTT client in device agent receives and handles the control request.

#### *a) Multiple Protocol in Single network Loop:*

The Authors are providing support to connect multiple serial communication protocols in a single RS-485 serial port. Usually, RS-485 port can communicate in any baud rate, and use any protocol such as Modbus RTU, BACnet MS/TP, etc., so users can connect devices supporting different protocol in a single port, which provides an additional flexibility and cost savings. Hence, it effectively reduces the need for separate converters for each protocol, since users can connect Modbus RTU and BACNET MSTP in the same device. Moreover, the need for additional slots in gateways devices is minimal since the same port is usable to access the devices supporting separate protocols using VSDACS.

The Authors have designed the Data Acquisition Agent in a modular fashion. It is possible to add support to other communication protocols by defining functions for 1) connecting to a device, 2) acquiring data, 3) writing control inputs.

#### *b) Data Acquisition Agent(DAQ)*

VSDACS acquires data from various industrial wired protocols such as Modbus, BACNET, OPC and wireless protocols such as ZIGBEE, LORA etc., and different physical interfaces based on the support of the IoT Gateway chosen. The Authors have designed Data acquisition agent in such a way that addition of new protocols in future and change of programming language of this component can be integrated with the rest of the system. The Authors used ZeroMQ [12] based messaging to achieve the data queue for data exchange which facilitates the development of protocol converters in languages such as C++ or node.js or Java and integrate to cloud posting agent. Besides data acquisition from OT protocols, a few systems provide access to data only through databases or plain-text files such as comma-separated values. The design of the DAQ agent allows connecting such systems, extract required data and send to the cloud posting agent for pushing data to cloud services such as AWS, Azure,TCUP etc. Device Control Agent has high priority over the physical interface to perform control operation with the assets. Sensor data acquisition has provision for data formatting options such as converting physical unit of measurement, to desired units that reduces the additional computational resources in cloud. This agent sends data to Local data manager and Cloud Posting agent through ZeroMQ.

#### *c) Flat File and DB Source agent*

In some cases due to security purposes the direct access to the industrial assets are not available. In order to extract data from such cases a separate data acquisition handler is required. Given that data can be provided either as flat file (in most cases CSV) or Database entries, the File and DB source handler must be capable of connecting and fetching real time data from the various types of databases as well as CSV files. In order to have a common interface to different databases for example SQLAlchemy in python is preferred to read data from database table based on the information taken from the configuration file. Besides, in some situations where the data provided as flat files like CSV, a separate handler is in place to read latest files and get the data.

### *B. Message Queue*

DAQ Agent acquires the data and send to Cloud Posting agent and Data Save Agent using an inter-process communication system. VSDACS uses ZeroMQ, which offers different channels of communication such as TCP, inter-process communication (IPC). The Authors configured the communication using IPC, when the processes are running within a Linux based device. In the cases, where the processes are running on separate devices in a distributed manner the TCP channel can be used. ZMQ supports encrypted communication using CurveZMQ library thus ensuring the security of information.

### *C. Cloud Agent*

Cloud Posting Agent receives the data sent by DAQ agent through ZeroMQ. It aggregates the data from different meters and adds the additional data about the building/device/assert if required. The received data is prone to modification upon requirement and pushes data to cloud services such as AWS, Azure, TCUP etc., using HTTPS, MQTTS based on the cloud product.

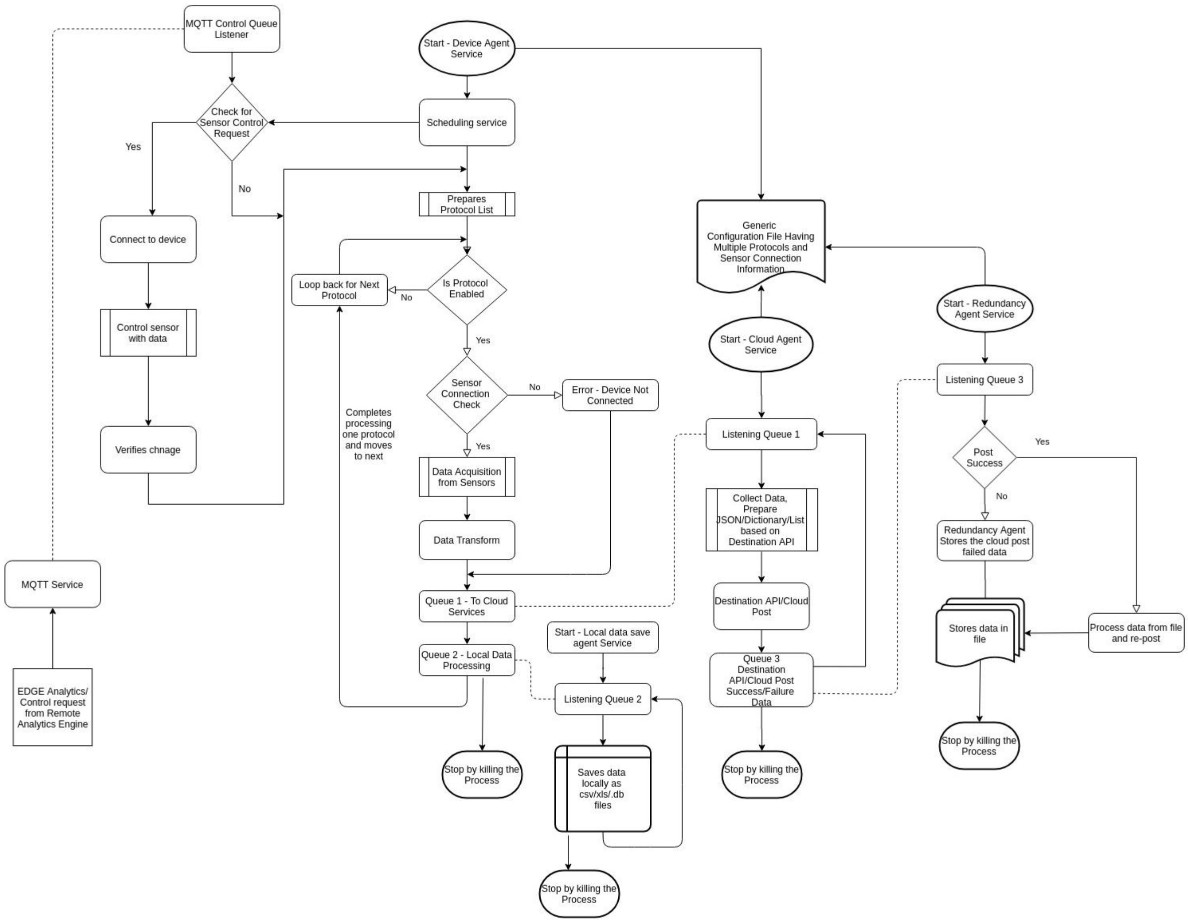


Fig. 3 VSDACS Algorithm Flow Diagram

### D. *Redundancy Agent*

This agent plays role to handle redundancy data during failure of cloud services or network error. Preventing data loss when facing errors in network is a necessary feature since the lost data would affect the data quality and hence the reliability of the prediction models. The Authors are creating temporary storage of data through either flat files or using the file-based database SQLite upon hardware requirements, in order to mitigate the data losses. The data will start posting to the cloud as soon as the network connection is available.

### E. *Local Data save Agent*

This agent provides option to save past days or weekly or monthly data locally for debugging purposes if required. In order to serve as a debug log and to support text-file based uploading of the collected data, a provision to store data in the form of a CSV file is given. This would enable the developers test and verify the data quality with the cloud data and it will provide a way to restore data in case the data in cloud is lost.

### F. *EDGE Analytics Agent*

This agent fulfils the Provision to take decisions and execution at IoT EDGE gateway level. This will be fruitful in industrial cases where immediate reaction to assets is required based on the received data rather waiting to receive feedback from Cloud Analytics Engine.

In addition to all above python agents, an exclusive Gateway Monitoring Agent is included in VSDACS design and is purely to monitor the health of the gateway where VSDACS and assets are connected. This agent has many services such as frequent polling of the live status of gateway and assets to remote Application, File archive in case of memory constraints, Remote File or Application push/pull, monitor the status of the running components and so on. This agent would be helpful in scenarios when huge no of gateways are deployed at different locations but needs quick accessibility.


Fig.3. Laboratory Setup - Sensors Connected to IoT Gateway

## V. EXPERIMENTAL AND FIELD TEST RESULTS

The design and performance of VSDACS observed in IoT gateway devices and industrial computers of various hardware specifications and operating system environments with python programming. It has been tested and deployed on machines running Windows, Ubuntu OS and Custom Yocto Linux Operating system. VSDACS has been successfully tested and deployed in fields on single arm cortex device Lantronix SGX5150, which is a 64 MB RAM device. The Authors have presented the results of VSDACS performance and data quality observed for the various environments. The Authors have monitored the performance of UDCAMS in various gateways based on the program execution speed, which does data extraction from different protocols through Data Acquisition Agent, data from DAQ to cloud through Cloud Posting Agent and local data save activities. The Authors found the memory utilization of all the agents of VSDACS combined together to be around 40MB RAM.

Assets with different protocols supported with same RS 485 physical interface was tested with VSDACS. In a single RS485 physical loop, The Authors connected BACNET MSTP supported Thermostat (Honeywell Model TB7600), Modbus RTU supported Energy meter (Schneider Electric EM6400 NG model) together and executed the VSDACS in the IoT gateways. Program Execution was smooth and successful as it could fetch the data without any issues. The Authors acquired data from different protocol supported devices namely BACnet IP Controller (Honeywell), OPC UA Server (Prosys), BACnet MSTP Thermostat, Modbus supported Energy Meter through single IoT gateway with VSDACS. Figure 3 is showing the actual lab setup with connections. This section also discusses business benefits of VSDACS implementation advantages to the end users.

TABLE II
**VSDACS PERFORMANCE IN DIFFERENT GATEWAYS**

| **Device Model and Operating System** | **Data Acquisition Rate (Seconds per data)** | | | |
|---|---|---|---|---|
| | **Modbus RTU** | **OPC UA** | **BACnet IP** | **BACnet MSTP** |
| LantronixSGX5150 & Custom Yocto Linux | 1.44 | 0.65 | 0.86 | 19.2 |
| Asus AaeonAIOT-IGWS01 & Ubuntu 14.04 | 1.32 | 0.51 | 0.73 | 8.55 |
| RaspberryPI 3 &Raspbian | 1.35 | 0.45 | 0.73 | 8.54 |
| Lenovo Thinkpad T430 & Ubuntu 16.04 | 1.25 | 0.31 | 0.72 | 7.08 |

### *A. Implementation on low memory devices*

Medium scale gateway are devices such as Raspberry PI and Intel atom based gateways with 1-2 GB of RAM, the data acquisition and control has sufficient memory to support data acquisition and control for about 100 devices. On devices having multiple serial ports, by running VSDACS, users can distribute the load connected to the device. Thus providing an option to connect to multiple serial networks and protocols in a single gateway device and communicate to them without any delay.

It is always in consideration while designing how VSDACS should behave even with low memory devices because purchasing cost for new gateway devices in implementation for small and medium scale industries will be major bottleneck. Successfully VSDACS executed with ease in low memory devices such as Lantronix SGX5150, which provides a RAM of 64MB and 128MB and Raspberry Pi 3B Model. While considering low specification devices, establishing communication with BACnet MSTP devices does take more time and for that, users have to increase the BACnet APDU timeout parameter. This is due to the requirement given by BACnet. BACnet MS/TP works based on token passing. The current Master, which has the token, sends as Poll for Master (PFM) signal. Master device must acknowledge this PFM signal within a specified time limit. Some operating systems that does not handle the BACnet process in high priority, which either causes a delay in BACnet communications or causes the BACnet communication to fail. One possible fix to this problem is to increase the priority of the BACnet process. For Lantronix gateway, authors have changed the process priority with the support of the product vendor and executed the complete VSDACS module with BACnet MSTP Thermostat. Here authors could achieve the data acquisition at 19.21 sec per data from earlier scenario of 50 sec per data without optimization. The data acquisition rate with Modbus, OPC and BACnet IP was high and no lag noticed with the devices. The CPU utilization rate observed to be around 9-to-15% while running VSDACS in SGX5150, a single core ARM CPU device.

### *B. Implementation on Medium scale IoT gateways*

Medium scale gateway are devices such as Raspberry PI and Intel atom based gateways with 1-2 GB of RAM, the data acquisition and control has sufficient memory to support data acquisition and control for about 100 devices. On devices having multiple serial ports, by running VSDACS, authors can distribute the load connected to the device. Thus providing an option to connect to multiple serial networks and protocols in a single gateway device and communicate to them without any delay.

### *C. Implementation in industrial PCs windows and Linux based systems*

In Industrial PC's, VSDACS can support approximately about 1000 devices/data point to acquire data in 15-minute interval for BACnet, OPCUA servers and Modbus devices. However, Windows Devices would not support BACnet MSTP as Windows implementation BACnet Stack library does not handle PFM and Token Passing signals. However, Linux system supports all three protocols that were tested.

### *D. VSDACS benefits to Business stakeholders*

VSDACS by its flexible programmable architecture and its performance in low memory devices benefits the small, medium and large scale-building stakeholders in continuous monitoring of energy utilities. Comparing with scenarios where proprietary BMS tools are required to acquire and control the sensors which involves high bill of materials for assessment and implementation than savings. Alternatively VSDACS provides low cost implementation, thus reduces Return on Investment duration. VSDACS has potential to acquire data from any third party monitoring tools with ease for further data modelling.

### *E. Comparison with LabVIEW data acquisition program*

The Authors do have other data acquisition system developed on National Instrument LabVIEW application. It acquires data from various Modbus slave meter connected to the NI module. The Authors have tested this system in various scenarios and observed LabVIEW as queue based monolithic application when compared to VSDACS. The comparison of VSDACS with LabVIEW based on the observation at out lab testing listed in table 3.

**TABLE III**
**COMPARISON BETWEEN SENSOR DATA ACQUISITION USING LABVIEW AND VSDACS**

| Feature | Labview System | VSDACS Supported System |
|---|---|---|
| Cost | Licensed product. Developing environment cost involved | Open source. Free of cost. |
| Memory | High memory requirement because of run time environment. Doesn't support low memory devices. | Less memory required. Only required packages memory. Supports low memory devices. |
| OT/IT Protocol support | Limited support for COAP,MQTT, BACnet etc. | New protocol can be included easily |
| Design Approac h | All modules should run simultaneously. | Agent based module. Modules run independently. |

## VI. CONCLUSION

The work described in this paper focuses on design and implementation of versatile application tool VSDACS for the application of monitoring and controlling the building energy consumption. From experiments, VSDACS deployed in IoT gateway or Industrial PC has capability to perform data acquisition from meters/sensors of various OT protocols. Although observed more execution time with process priority constrained protocol like BACnet MSTP in low memory devices, there were no issues with VSDACS implementation. VSDACS also addressed the data acquisition from flat files or DB. The Control feedback values can be sending either from cloud based analytics services or from edge analytics. VSDACS provides an edge-based analytics solution placeholder, which reduces the computation time receiving feedback from the centralized analytics services in remote servers. While deploying a large number of Edge IoT Gateways, there arises a need to have a centralized system to manage the gateways remotely and Gateway monitoring agent in VSDACS fulfils the same. Hence, VSDACS fulfils the need of an low cost programmable interface required to achieve real time monitoring of energy utilization in buildings with control features and its design very likely be adopted to any domain in IoT for continuous monitoring of systems.

## ACKNOWLEDGEMENT

The work presented here is outcome of the research activities conducted at Sensors to Software, TCS Innovation Labs within the Energy Management

Solutions domain with continuous support and encouragement from Mr.Sriram Krishnan, Mr.Mehal Shah and co-associates of the S2S lab.

## REFERENCES


[1] M.Pipattanasomporn, M. Kuzlu,W. Khamphanchai, A. Saha, K. Rathinavel and S. Rahman, (2015). "*BEMOSS: An Agent Platform to Facilitate Grid Interactive Building Operation with IoT Devices*".IEEE Innovative Smart Grid Technologies 2015 - Asia (ISGT ASIA), DOI: 10.1109/ISGT-Asia.2015.7387018

[2] AdityaNugur, M. Pipattanasomporn, M. Kuzlu and S. Rahman, (2018)."*Design and Development of an IoT Gateway for Smart Building Applications*". IEEE Internet of Things Journal, DOI: 10.1109/JIOT.2018.2885652

[3] W. Khamphanchai, A. Saha, K. Rathinavel, M. Kuzlu, M. Pipattanasomporn, S. Rahman, B. Akyol and J. Haack, (2014).*"Conceptual Architecture of Building Energy Management Open Source Software(BEMOSS)"*. IEEE PES Innovative Smart Grid Technologies, Europe, DOI: 10.1109/ISGTEurope.2014.7028784

[4] Manuel Mazzara, IlyaAfanasyev, Smruti R. Sarangi, Salvatore Distefano, Vivek Kumar, Muhammad Ahmad, (2019). "*A Reference Architecture for Smart and Software-defined Buildings*". IEEE International Conference on Smart Computing (SMARTCOMP), DOI: 10.1109/SMARTCOMP.2019.00048

[5] Nutthaka Chinomi, Monthon Leelajindakrairerk, Suttipong Boontaklang, Chow Chompoo-Inwai (2017). *"Design and Implementation of a smart monitoring system of a modern renewable energy micro-grid system using a low-cost data acquisition system and Lab VIEWTM program*".DOI:10.1080/22348972.2017.1345226

[6] Vangelis Marinakis, H. Doukas, (2018). "*An Advanced IoT-based System for Intelligent Energy Management in Buildings*".https://www.ncbi.nlm.nih.gov/pubmed/29462957, DOI: 10.3390/s18020610

[7] Luis Gomes, Filipe Sousa, Zita Vale, (2018). *"An Agent-Based IoT System for Intelligent Energy Monitoring in Buildings"*,DOI: 10.1109/VTCSpring.2018.8417868

[8] Sangmin Park, Sanguk Park, JinsungByun, Yeong Yu, Sehyun Park Chung-Aug University. "*Design of Building Energy Autonomous Control System with the Intelligent Object Energy Chain Mechanism Based on Energy-IoT"*, DOI: 10.1155/2015/931792.

[9] Dimitrios Amaxilatis, Orestis Akrivopoulos, Georgios Mylonas, and Ioannis Chatzigiannakis. "*An IoT-Based Solution for Monitoring a Fleet of Educational Buildings Focusing on Energy Efficiency*" DOI: 10.3390/s17102296

[10] Dhiman Chattopadhyay, Abinash Samantaray, Anupam Datta, (2017)."*Device Microagent for IoT Home Gateway. In Proceedings of Advances in IoT ,Architecture and Systems",*(AIoTAS'17), 8 pages.

[11] Nutthaka Chinomi, Monthon Leelajindakrairerk, Suttipong Boontaklang &Chow Chompoo (2017). "*Design and Implementation of a smart monitoring system of a modern renewable energy micro-grid system using a low-cost data acquisition system and LabVIEWTM program*".DOI: 22348972.2017.1345226

[12] Zero Message Queue (ZMQ) http://zeromq.org/

[13] MQ Telemetry Transport (MQTT) http://mqtt.org/

[14] Building Automation and Control Networks (BACnet) http://bacnet.org


## AUTHORS PROFILE

**Ashok Kumar Renganathan** working as an IoT EDGE Researcher at Sensor to Software, TCS Innovation lab, Chennai, India. He received his Master degree in Photonics from Manipal University. His work involves solving problem towards achieving low cost implementation of smart sensor control and integration with various IoT Cloud platforms to address various industry problems using data analytics approach.

**Nethaji Kochadai** working as an IoT Edge developer particularly in Energy domain. I have industrial experience in Retails, Buildings, Steel manufacturing and Auto mobile manufacturing. The current focus is to develop holistic application on Data acquisition and control system using various protocols.

**Sakthimurugan Chinnaramu** has been associated with TCS for more than 11 years in Engineering and Industrial Services (EIS) & Internet of things (IoT) space. He has Master degree in VLSI Design from College of Engineering, Guindy- Anna University Main Campus, Chennai, India. He has expertise in IoTend to end layer design and implementation that include various IoT platforms like Azure, AWS, IBM Watson etc., and Focused on edge and security enablement.