IoT Body of Knowledge

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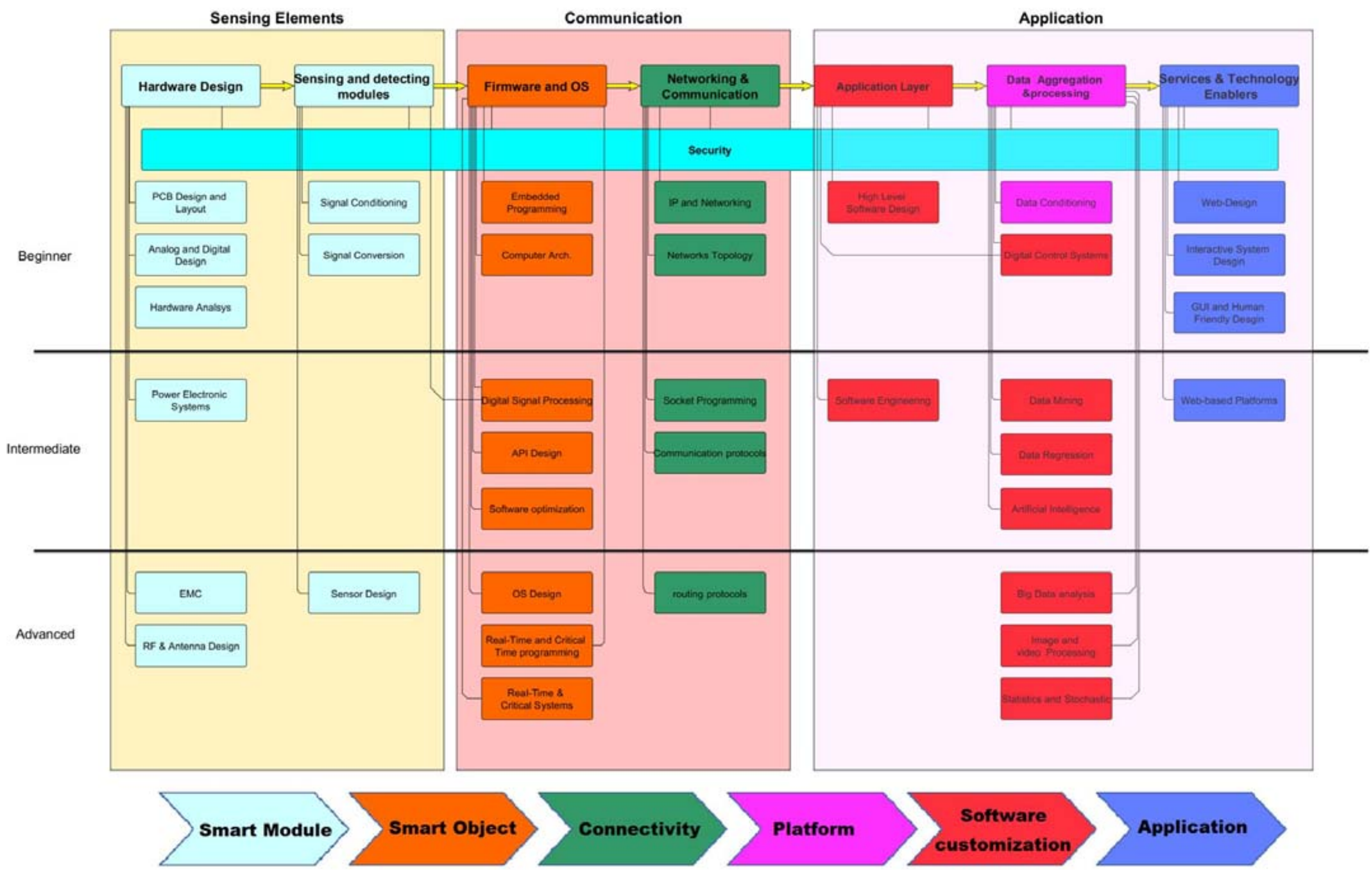
1. INTRODUCTION

The IoT BoK is developed by the IoT Egypt Forum IoT BoK workgroup targeting developing a guide for IoT core knowledge areas and the required curriculum to prepare competent IoT experts for the market. The IoT BoK introduces an integration between the key knowledge sources and references of the IoT, organized and demonstrated to support all stakeholder with main focus on the Egyptian market. It is a constantly evolving content that is adjustable by community to reach the best perception that serves the IoT community.

2. IOT CORE KNOWLEDGE AREAS

The below figure summarizes the IoT suggested knowledge areas and their mapping to the IoT value chain.



This figure depicts the areas of knowledge needed to have an IoT product from scratch, starting from the hardware design moving through the network structure and communication protocols, reaching the application layer and the data visualization techniques. These topics are all related to the business model for the IoT market that is going to be the driving force for both industry and academia to invest and research. So, to reach this goal the IoT Egypt Forum IoT BoK workgroup conducted the previous map. The suggested knowledge areas are classified in 3 main regions as follows:

1- Sensing Elements
2- Communication
3- Application

These regions are further extended into sub-classes or categories to enhance the specificity and details of the proposed structure. Also the figure shows a horizontal classification as beginner, intermediate and advanced respectively. These levels indicates the level of details, sophistication and difficulty required to master these topics. The following subsections are going to describe in details the figure and illustrate the indicated topics.

1. *SENSING ELEMENTS*

This is hardware oriented topics, indicating the tasks and knowledge of design and fabrication of sensors, hardware (i.e. daughter and mother) boards for the sensor that suites the requirements for the IoT.

1.1. HARDWARE DESIGN

This includes all the topics related to the board design and fabrication from the electronics and power management perspective.

1.1.1. HARDWARE ANALYSIS

It is the ability to analyze, design and implement the hardware electronic circuits as a solution for a given task or problem, including on-shelf solutions or custom design (i.e. IC's and discrete components).

1.1.2. PCB DESIGN AND LAYOUT

IoT industry requires deep understanding for the Printed Circuit Boards (PCB) manufacturing and design, knowing the substrates of the PCB and how to make a good use of multi-layer boards, also designing boards that support mixed signals, high frequency, etc. Also routing techniques and layout optimization is needed to minimize the boards form factor and foot print.

1.1.3. ANALOG AND DIGITAL DESIGN

Most of the sensors known nowadays are analog sensors that are then converted to digital form, knowing both analog and digital electronics design techniques would help the designer to find better techniques for solving the requirement as well as optimize the design.

1.1.4. POWER ELECTRONICS

Understating the concepts of switching mode power supplies and converts (i.e. DC-DC converts). Also knowledge about power consumption optimization to increase the life time, as most of the IoT sensor boards are battery powered equipment.

1.1.5. RF AND ANTENNA DESIGN

The capability of designing and implementing Antenna and RF backend for boards in different frequency ranges and bandwidths. Deep understanding for antenna basics and design parameters. The understating of antenna types (i.e. wire, PCB, Chip antenna). Designing of matching network and layout. Testing the performance, antenna tuning and frequency isolation.

1.1.6. EMC

Electromagnetic compatibility for the designed boards and IoT systems in order to provide a grade of safety against electromagnetic interferences. Covering the main classes of EMC as Emissions from the designed/on-board antenna, the susceptibility of the IoT system and its vulnerability to RF attacks and the immunity of the IoT system to remain functioning.

1.2. SENSING AND DETECTING MODULES

This includes the topics related to the sensors, its signals and design.

1.2.1. SIGNAL CONDITIONING

Understanding the techniques and methods of signal conditioning such as amplification, filtration, isolation, stabilization, etc., that make the signal ready for conversion and thus for further processing.

1.2.2. SIGNAL CONVERSION

Understanding the techniques and methods of signal conversion from analog to digital (ADC) and vice versa. This includes the selection of the appropriate ADC design and width, as well as calculation of conversion time and reference voltage required. The same applies also in DAC in case of actuators control signals (if needed).

1.2.3. SENSOR DESIGN

Sensors and transducers are used widely to detect different environmental phenomenon. These phenomenon are diverse in their nature and the methods used to detect them, here comes the role of selecting the method of sensing and the design of how the sensor is going to work. Sensor design encompass the sensitivity and sensor specification as well as the sensor calibration. Many researches are conducted in this field based on the evolution of Nano-technology (i.e. Nano-sensors) and MEMS.

2. *COMMUNICATIONS*

This is the software and firmware related topics, including the embedded programming of the IoT devices and the communication stacks that are used in these networks. The software in this layer focuses on the entity of the IoT devices themselves and the communication between these entities. The upper layer application and the intelligence based on the collected data from these IoT devices are out of scope of this knowledge area.

2.1. FIRMWARE AND OS

This section introduces the topics that are needed by the IoT device as a standalone device including the firmware for the processors on the node and the operating system if available.

2.1.1. EMBEDDED PROGRAMMING

Understating the concepts of low level and embedded systems programming. This includes code optimization and resource management techniques for bare-metal and resource constrained programming environments.

2.1.2. COMPUTER ARCHITECTURE

Understanding the methods and concepts that describe the functionality, organization, design and implementation of computer systems, leading to optimize the performance, price and resources needed by the IoT device to accomplish its functionality over the desired life-time.

2.1.3. DIGITAL SIGNAL PROCESSING

Many IoT devices are sensor based devices that need to aggregate the sensor values and convert to valuable data. This data may need to be processed in different domains such as time, frequency or space. This may include linear and non-linear operations. This knowledge area is strongly related to signal conditioning and signal processing fields that are shown under sensing and detecting modules knowledge area.

2.1.4. API DESIGN

Application Programming Interface (API) design is intended to provide reusable functions and routines without being exposed to the complexity of implementation. Good API design promotes the code readability, usability and minimizes the development time. Many recommendations are given in this topic, relating to these recommendations will enrich the development of IoT coding and platforms.

2.1.5. SOFTWARE OPTIMIZATION

IoT platforms and devices are generally resource limited, so understating the optimization techniques and solving the tradeoffs in software design would help facilitating the IoT platform functionality. Thus understating the software optimization on different levels such as software design level, algorithms and data structures, build level, etc. is needed.

2.1.6. OS DESIGN

Understanding the concepts of operating system design, dealing with different layers of the operating system and different types, either fully featured operating systems or Real-Time Operating Systems RTOS. Some advanced IoT tasks require modification in the underlying operating system, or even a design for an operating system from scratch for advanced and largescale projects.

2.1.7. REAL-TIME AND CRITICAL TIMING PROGRAMMING

Understanding the concepts of proactive and reactive system programming that responds to either internal or external events in timed deadlines.

2.1.8. REAL-TIME AND CRITICAL SYSTEMS

Understanding the design concepts of proactive and reactive systems that are responsible for responding to either internal or external events in timed deadlines.

2.2. NETWORKING AND COMMUNICATIONS

This section introduces the topics that are needed by the IoT devices to communicate with each other, including the network concepts and traffic management.

2.2.1. IP AND NETWORKING

Understanding the Internet protocols and network designs and protocols, across all layers, physical, MAC, IP, etc. This include the understanding of OSI Layers and different protocols related to each layer.

2.2.2. NETWORK TOPOLOGY

Understanding the different networks topology and structure, and the network management techniques used in each topology. The IoT devices arrangement and functionality may require different network topology and access control and management.

2.2.3. SOCKET PROGRAMMING

This is a programming related concept, at which implementing at the code the end-point for send and receiving packets. This encompass implementing multiple connections on some IoT devices. Also this concept is extended to the server back end side of the IoT system where the data is received, processed or sent.

2.2.4. COMMUNICATION PROTOCOLS

Communication protocols are crucial for the IoT systems (i.e. Wi-Fi, ZigBee, Lura , Sub 1G wifi, BLE). IoT systems are different according to their requirements and application, which leads to a different set of priorities of the communication protocols regarding the band-width, speed, connectivity and accessibility. Thus making the deep understanding of different communication protocol a key factor in designing any IoT system.

2.2.5. ROUTING PROTOCOLS

Routing protocols are important in the final performance of the network, it about how the packets are going to reach their destination, and selecting the optimum route. Selecting, optimizing or even designing a protocol from scratch is a key-factor and needed in IoT systems.

3. *APPLICATION*

This includes all the topics related to the system overall performance and functionality. The IoT system is about delivering a valuable information to the globe, and this section conduct the topics about converting the raw data received from the IoT devices to a data on servers and making it accessible.

3.1. APPLICATION LAYER

This section includes the topics related to the server side back-end software design and implementation.

3.1.1. HIGH LEVEL SOFTWARE DESIGN

Understanding the process of developing software product, through providing an overview over the system, identifying the main components and attributes of the system and showing the system architecture.

3.1.2. SOFTWARE ENGINEERING

It is "*the systematic application of scientific and technological knowledge, methods, and experience to the design, implementation, testing, and documentation of software*" according to the Bureau of Labor Statistics, IEEE Systems and software engineering – Vocabulary

3.2. DATA AGGREGATION AND PROCESSING

This section includes the topics related to the system intelligence and data analysis

3.2.1. DATA CONDITIONING

It is the usage of data management and optimization techniques to improve the data centers and storages to improve the system utilization and performance. as IoT is going to be the main contributor of the data generation of the world in the few next years, data conditioning techniques are going to be crucial to help lowering the operation cost of data centers and enabling to compress and utilize more the storage space already available.

3.2.2. DIGITAL CONTROL SYSTEMS

IoT is not only about collecting data, but also acting upon it. Digital control systems is a branch of control systems where digital components (i.e. computers, micro-controllers, etc.) is taking the action. Digital control systems include a combination of some aspects that are already discussed previously as embedded programming, digital signal processing. Moreover, the concepts of control system is to be applied as system stability, system response, etc.

3.2.3. DATA MINING AND BIG DATA ANALYSIS

Data mining is the process of analyzing hidden patterns of data according to different perspectives for categorization into useful information, which is collected and assembled in common areas, such as data warehouses, for efficient analysis, data mining algorithms, facilitating business decision making and other information requirements to ultimately cut costs and increase revenue.

3.2.4. DATA REGRESSION

Regression analysis is a form of predictive modelling technique which investigates the relationship between a dependent (target) and independent variable (s) (predictor). This technique is used for forecasting, time series modelling and finding the causal effect relationship between the variables.

3.2.5. ARTIFICIAL INTELLIGENCE

It is the simulation of human intelligence process by computers that includes learning reasoning and self-correction. Artificial intelligence (AI) can be classified as weak AI (used for particular tasks as speech recognition and so on), and Strong AI that simulates human cognitive abilities. The IoT data is trended to be based to AI system to make endless usage of these data and facilitate, predict and improve human's life. AI includes but not limited to Machine learning, Computer vision, natural language processing, etc.

3.2.6. IMAGE AND VIDEO PROCESSING

This is the process of analyzing and extracting information from images and video stream. This includes various techniques of image filtration, pre-processing, segmentation, feature extraction and so on.

3.2.7. STATISTICS AND STOCHASTICS

Statistics and random process statistics are the science of mathematics dealing with distribution and modeling of the systems showing the trend of the data/system that lead to better prediction and control tuning for the system. Stochastics are more used for random and complex systems. Both fields are heavily used

3.3. SERVICES AND TECHNOLOGY ENABLERS

This section include the topics that are not mainly in the core of IoT system, but actually a supporter/ enabler technology that IoT may use.

3.3.1. WEB-DESIGN

Web design is used to interface the information gathered from the IoT system to the globe through web-pages that grantee easy access. Web design encompass different talents and technologies, as html, ccs, javascript, nodejs and many many other tools. This topic is also meant to include the both UI and UX.

3.3.2. INTERACTIVE SYSTEM DESIGN

Interactive system design conceder the user of the system as part of the system and respond according to his input and interaction, this could appear in the web-based applications and games. This concept uses different methods to be achieved, one of these which is the most important is the concept of usability engineering, that grantee the functionality, efficiency, safety and user experience in the process of design and usage of the system.

3.3.3. GUI AND HUMAN FRIENDLY DESIGN

Design of a graphical user interface that is well suited to the human is not a mysterious task. Human engineering factor is a science that is built specially to encompass the user's psychological concepts and trend, to help the designers finds the best options for colors, fonts, icons, etc. that makes the user feels OK with it, and thus reduce the human error while usage and enhance user comfort.

3.3.4. WEB-BASED PLATFORMS

There are a lot of platforms that enrages nowadays to help and contribute in the life of the IoT industry. These platform may be used to enhance the experience of IoT system design, minimize the time-to-market, or to improve the quality of the product, for example IBM Watson is one of the most well-known IoT platforms available nowadays, and others a lot to come later. But, IoT is still a developing technology that didn't reach the maturity level yet, so being attached to single platform or technology would narrow the process of learning, development and innovation.

4. SECURITY LAYER

The Security layer is added as an entity crossing all the sections, this is due to its importance and involvement in all sections. IoT is going to be the giant data contributor and generator, and meanwhile many critical decisions in our life are goint to be influenced by these data, so security in to be granted on all levels in IoT system. Hardware security concerned about securing the board and physical buses on the board from intruding unauthorized data, or hacking the sensor systems that lead to false measurement. Software security, it is concerned about the integrity of the system, so that no one could update the firmware of the nodes remotely unintentionally or unauthorized access to the firmware and functionality of the board. Moreover, the software security includes the cyber security of the board and the remote access to the sensor or sniffing the data.

5. *VALUE CHAIN*

The proposed Value chain puts the Egyptian market in consideration. Showing the key-players in the IoT market and relating it to the proposed knowledge areas. As mentioned, IoT market embrace different technologies that make the player in the market came from different backgrounds. This is one of the market strengths of IoT, that no one have provided an end-to-end IoT solution, this making the value chain and the market model of IoT attractive for all investors. The figure depicts 6 different key-players in the market:

5.1. SMART MODULES AND SMART OBJECTS

Entities and companies that provide the hardware devices, either the sensing elements (sensors) or the hosting hardware (i.e. boards and processing units) are the basic enabler and provider of this market. Unfortunately, Egypt market lakes a lot of key-players in this part, however, investments in designing and fabrication would pay-off. According to different models and estimates, hardware vendors are going to gain about 10-20% of the market value of the IoT systems. Also IoT systems are already inspired by the evolution of technology in these 2 parts.

5.2. CONNECTIVITY

Connectivity is the heart of the IoT systems, IoT systems depends over various method of connectivity techniques, but at the end most of them require an internet connectivity may be not on the level of every node, but over the level of aggregator nodes. Connectivity provides are meant to be the ones of the greatest share in the market value, either through internet service providers (ISP) or mobile network operators, both have to customize and provide solution for the IoT systems that are going to invade their band-width and networks. ISPs and Mobile network operators have to provide usage models for the IoT systems inspected by Machine to machine (M2M) profiles which differs greatly from the Human to Human (H2H) and Human to Machine (H2M) profiles.

5.3. PLATFORM

Platform is the real differentiator in the IoT industry. Platform providers are integrating the hardware part (Smart modules and smart objects) with the connectivity service providers to achieve the essence of a system. Platform is a generic concept that defines a software/embedded platform for the devices that focuses on processing and hardware interfacing, or a communication platform either cellular or WiFi that off-load the developers from the connectivity burden. Most of investors in the IoT market are located here, in the Platform group. This definitely shows the importance and the value share of this group. Platform providers could search for an alias with some hardware providers/vendors and may be a connectivity provider to achieve an integrated solution which could increase significantly their value share.

5.4. SOFTWARE CUSTOMIZATION

Also could be related to system integrators, they have a big role in the IoT industry as it is not about plug-and-play solution. As mentioned earlier, IoT market is composed of different entities came from different backgrounds, that making gluing all these entities together to provide seamless operation of the system is an add-value to the IoT market.

5.5. APPLICATION

This is the top level of the IoT system, and where customers are attracted to pay their money to get a service. However this portion of the market is not as large as others. But this is the direct add value to the customers. Startups and small business could invisit in this portion, generating smart solutions and ideas,

3. SUGGSETESD IOT BOK STRUCTURE

Based on the proposal of the IoT knowledge areas introduced in the previous section also considering their alignment to the IoT value chain, below are the suggested structure for the IoT Bok:

- Introduction to IoT
- IoT Applications
- IoT Knowledge Areas
- Communication and Connectivity
- Cloud and Big Data
- IoT Software and Hardware
- IoT Security
- IoT System Design
- IoT System Testing
- IoT Business Model