A framework for rapid integration of IoT Systems with industrial environments

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***Abstract*— we have devised a framework to facilitate the deployment of an IoT-based system running in industrial environments. The aim is to minimise development and testing time while abiding with standards and needs. We take the view that efficient adoption of IoT in industrial environments should be treated as a multidisciplinary issue and should be carried out in relatively small steps to minimise risks and disruption. Our method approaches this problem with a holistic end-to-end point of view stretching from sensor devices to interfacing with the final user where all software and hardware elements of the system are being considered and addressed.**

Keywords— Industrial IoT, end-to-end application development

I. Introduction

While the value of IoT applications for industry is indisputable, there are still unanswered questions on how the introduction and integration of IoT can take place to improve-and not jeopardise- existing, running industrial production systems. Such systems can afford little or no interruption or disruption. They incorporate third party applications that although fit for purpose may not offer a standardised API or SDK for an IoT application to exchange data and instructions. Moreover, they can rely on a excess of technologies in components ranging from different communication protocols (wired, wireless), operating systems, data repositories (SQL/NoSQL databases, file systems) to security protocols and interfacing devices (tablets, smart phones, touch monitors).

On the top of these constraints, each industrial environment has a number of diverse and context-specific requirements that IoT technologies are called to resolve. Even within the same setting, these may vary from electronics and data communication through to data storage and availability to data analysis and prediction and user experience.

As a result, introducing IoT in the industry is a risky endeavour with multiple possible points of failure: The technical solutions may be incompatible with pre-existing equipment, unsuitable for the given usage (environment, accuracy, speed, latency) or increase the workload as part of configuration, maintenance and operation. Furthermore, the proposed solution may not fulfil design requirements hence answering irrelevant or insignificant questions, not extracting available knowledge by data analysis and not delivering the optimum user experience. Any of the above could lead to the insufficient usage of IoT-based improvements and their eventual abandonment.

The objective of our effort is to organise the tasks and skills required so as to deploy an IoT platform in an industrial environment rapidly and without problems. We seek to achieve this while tackling the difficulties and constraints outlined above.

Our work of this paper derives from our experience in deploying small and medium scale IoT solutions in various domains (agriculture, health, manufacturing, water and energy) and in industrial and community settings. Obviously large scale deployments present additional challenges (e.g. network traffic, complex middleware, maintenance and recovery etc.) It is however our strong belief that successful deployment and usage of IoT by Small-Medium Enterprises (SMEs) is a critical factor to accelerate the adoption and evolution of IoT.

Section one outlines the rationale of our work and is followed by a survey of related work. The next section discusses the particularities of IoT applications for SMEs. We then list the different layers of the IoT-based architecture and focus on the business-related layer. Referring to this structure, we define user roles and development stages and allocate tasks to each one. Finally, we outline two existing case studies and argue the conclusions and future work.

II. Related Work

Various efforts surveyed in [1][2] have been expressed to model the adoption of IoT in an industrial setting. Most of them follow a technically oriented approach and their structures are based on technical layers. Their validity has been tested against specific case studies (e.g. Smart cities [3]), yet this is still ongoing research towards consolidating a unified solution especially as new technologies continuously come into play. The relationship between the readiness level of new technologies and the maturity of an IoT platform is discussed in [4]. An interesting tactic is to develop recipes for designing IoT systems such like patterns for software systems [5]

The business element of IoT systems is discussed in [6], including concepts such as value proposition, customer relationships and costs which [7][11] maps to building blocks and user roles. [8] goes a step further and proposes an integrated digital service-oriented architecture with business and technical viewpoints. All these efforts indicate that business models for IoT are still being developed because of the disruption IoT is bringing into businesses.

III. IoT for SMEs

A small/medium deployment is defined first by the size of the hosting enterprise as this may be the reason for limited available resources (monies, expertise, time) and second by the size of the deployed solution (number of sensors, size of area, services, applications)

One major requirement for a deployed IoT Solution in an SME domain is that it should be straightforward to support, manage and deliver immediate visible benefits. However, IoT is still a complex field even for researchers so it can easily cause a huge burden to a company's technical staff introducing additional complexity and workload. Issues such as service (un)availability, inconsistent or inaccurate sensors, devices that require change of batteries frequently, gateways that lose connectivity or a GUI that does not match the personas of the end-users will result to mistrust and abandonment of the solution because it disrupts everyday operations and demands additional workload in probably unknown and multidisciplinary technical fields.

Consequently, an IoT solution that is potentially advantageous and can provide effective insights and services many not be adopted regardless of the business needs if it fails this requirement. The approach preferred by the authors of this paper is to prioritise the success of small, feasible operations over larger step changes. The risk of large operations often outweighs the associated advantages.

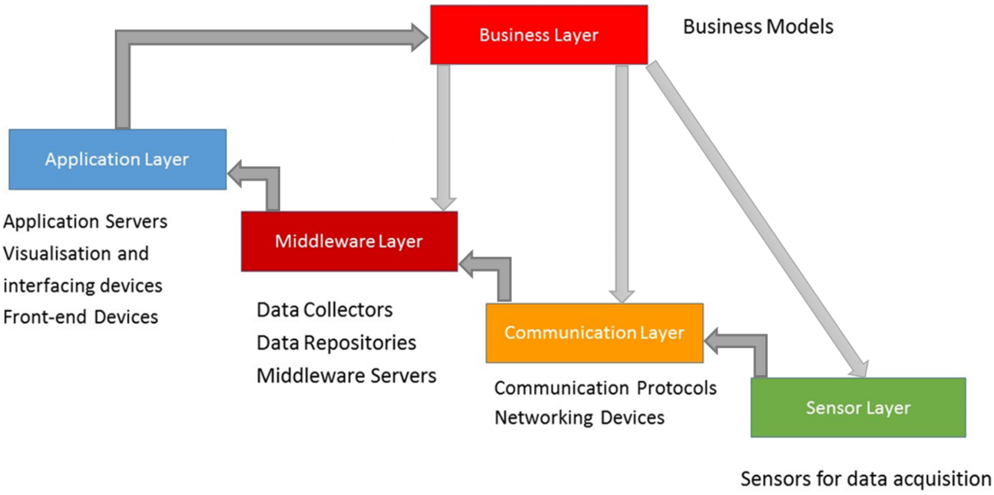

Fig.1 Layers for organising tasks for development and deployment

IV. An Architecture for Industrial IoT

There already exists a number of research works specifying architectures for platforms with both technical and application-specific orientations. We extend the organizational layers discussed in [1], outlined below (also Fig.1) so as to form the basis for further analysis

1. Sensor Layer (SL)

   Any set of devices used for data acquisition; could be environmental (temperature, light, CO_2), location (GPS, BT Beacon, PIR), equipment specific (energy, usage, vibration) and identifiers (RFID). The minimum requirement for each device is to produce an identifier (UUID). This layer is responsible for generate sensor data and device information (e.g. battery life) and receive configuration updates.

2. Communication Layer (CL)

   The data exchange between the sensor and the middleware layers with wireless (Wi-Fi, BT, LoRa, Zigbee) or wired technologies (Ethernet, RS-232) and IoT related stacks (MQTT). For a full list of available technologies see [10]. It is also concerned with network configuration and performance.

3. Middleware Layer (ML)

   The components to handle data and manage communication and sensor activity. It includes messaging queues (MQTT, AQTT), back-end servers, database repositories (SQL/NoSQL) and connectors among these components.

4. Application Layer (AL)

   Any set of applications that can convert data into insightful information and knowledge and present it in an appropriate interface. It includes appropriate for context-of-use devices (tablets, touch screens) delivering a user experience compliant with the nature of each application, e.g. Visualisation of machine utilisation, alert notifications.

   These four layers refer to technical matters. We introduce an additional layer to cover business related elements. We take the view that completion in introducing IoT cannot be fulfilled by technical success only. Any work will be undertaken under corporate constraints and guidance by senior management who needs should be on board and support it.

5. Business Layer (BL)

   Business aspects such as specification of the return of investment, evaluation of the disruption to business and production processes, project management and development of a technical road map preferably under a staged iterative approach so as to measure benefit and minimise risks. This non-technical layer drives the nature and sequence of work in all other layers.

The size and complexity of each layer depends on each case study. For example the computational power, sensors and displays available these days imply that for minimum applications even a smart phone could sufficiently cover many tasks in the technical layers.

V. Stages, Skills and Activities

Having this structure of the system provides us with the foundation to undertake the activities listed below to implement it. These activities have their place into three stages of deployment namely,

1. Investigation

Concur on resources available, issues of interest and corresponding solutions under constraints posed by existing running system.

2. Validation

Specify a test bed, develop the solution while taking into account the minimisation of disturbance to any running of production environment.

3. Installation

Migrate the solution to the live environment, deploy, and support.

These stages require the involvement of the following skill sets:

- Business Analyst (BA): to specify the business value from IoT deployment, manage disturbance, approve costs and human resource allocation and supervise planning.
- System Administrator (SA): ensure and implement solution to be compliant (e.g. Certifications and security requirements) and quality assured for operation.
- Application Architect (AA): design the end-to-end solution to meet the requirements of the BA and the constraints of SA and own its implementation by developers and technicians.
- Quality Control Engineer (QCE): Evaluate the solution and approve its commission.

Stage	Layers	Skillset	Task	Description	Deliverable
Investigation	SL	BA, AA	T1	**Existing and desirable sensors** Types and mode of installation	Specification of type sensing devices to use and their installation in the production environment
	CL, BL	SA, AA,	T2	**Existing IT Infrastructure** Operating Systems, Databases, Messaging Queues, Application Servers, LDAP	Definition of available software tools to use and existing software compatibilities Identification of incompatible technologies
	CL,ML	SA, AA	T3	**Security requirements and procedures**	Network configuration for additional IoT services
	CL	SA, AA	T4	**Networking, availability and range, configuration**	Specification of network configuration
	AL, BL	AA, BA	T5	**Reporting** Requirements and format for data aggregation, filtering and visualisation	Documentation of reporting requirements
Installation	All	QCE, AA	T6	**Development of test bed**	A virtual and gradually simulated installation that enables testing and review of user interface.
	SL	SA	T7	**Installation of sensing devices** According to decisions of T1-T4	New/modified devices installed and operative
	CL	SA	T8	**Reconfiguration of Network** According to decisions of T1-T4	Modified network documented and operative
	ML	AA	T9	**Implementation and integration of Middleware** On test bed and live platforms	Code operational on development, staged and live environment
	AL,ML	AA,BA	T10	**Development of application logic** Following T5	Documented code repository
	AL	AA,BA	T11	**Development of GUI** Following T5	User Experience report, GUI Implementation
Validation	SL, ML	QCE	T12	**Specification of Test Suits**	Specification of procedures and acceptance criteria
	SL, ML	BA, AA	T13	**Specification of gradual deployment** Complying with T12	Planning of transition from virtual to live environment
	BL	AA	T14	**Documentation and support plan** Technical and business documentation	Report compliant with Standards
	BL	AA, SA	T15	**Production Release**	Live Platform
	BL	AA, BA	T16	**Post production Monitoring**	Evaluation of benefits Detection of production deficiencies Specification of next actions

Table 1: Skills per Phase And Layer

VI. Stages, Skills and Activities

Having this organisation of a system provides us with the know-how for planning activities and allocation of personnel for their execution. Table 1 lists these activities that belong in an abstract level which any project plan may comply with.

The majority of the activities demands the incorporation of multiple skillsets. This is necessary to achieve task deliverables and also promotes inter-team communications and diversifies the skills of business and technical personnel.

The significant points to note on these activities are:

1. Specification of a Test-bed

The development of a test bed facilitates the gradual shift from a virtual environment to a real one. The starting point is a simulated environment where data collection is replicated as well as all parts of the platform (e.g. Digital twin approaches [12]). Progressively, as development matures and tests are executed and satisfied, these parts are replaced by ones of the production environment.

For instance, using the production database necessitates stability and load tests, reading data coming from sensors and producing reports with real data that facilitate usability assessments.

2. Using the cloud

Adopting cloud-based services is a priority [2], especially cloud managed services. Cloud services are cost effective, lessen the responsibility for maintenance and security. Still, there can easily exist environments where for various reasons, outgoing traffic is permitted thus a local installation should be developed. Depending on each use case provision must be taken for a flexible architecture than can be migrated to the cloud.

3. Evaluation and planning of next actions

This whole set of tasks can be considered as a single step in an iterative process for IoT adoption. As mentioned above we support a gradual embracing and the last task aims to first evaluate a deployment, identify any issues on production that it may reveal (underuse of machines, downtime patterns) and trigger a new phase of development to address them.

VII. Case Studies

A. *Smart Shelving*

The goal of smart shelving was to monitor boxes placed and removed from shelves. Processing of boxes should follow a certain sequence determined by the factory floor supervisor. Each box was equipped with an RFID tag (T1). The investigation stage identified strict security regulations (T3); no network connectivity outside the premises and all infrastructure under Microsoft products hence any solution should be implemented (T2) with .NET and any plug in products (e.g. RFID SDK) should work with .NET.

A series of applications (T10, T11) were developed to drive the sequence of box processing. Development (T13) took place in a sample shelf (T12) which was validated in a testing line before being deployed in the factory (T15). The data produced highlighted bottlenecks (T16) and triggered the investigation of a data analytics project for further optimisation. The overall architecture is shown in fig. 2.

B. *Environmental Analysis and Monitoring*

A device to perform environmental monitoring in remote locations was already in place and performed to specification (Fig.3). Data were sent through 2G to a messaging server running on an EC2 instance on AWS and stored in an EC2 MySQL instance. A web application provides a user interface for data visualisations. There were requirements for 3G data communication, the optimisation of AWS usage and the monitoring/maintenance of the platform. The investigation stage identified the parts of a cloud-based architecture to upgrade the system (T2), provide stability and automate maintenance tasks (T4 such as database backup. Using the cloud (T8) also facilitated the migration from a development and testing environment (T12) to the live one, thus easing validation and minimising development time (T9).

The result (T15) enhanced the skills of the team with cloud configuration (T14) and led to a subsequent project on anomaly detection (T16) using cloud resources on machine learning.

VIII. Conclusions and Future Work

IoT solution development and deployment is a multidisciplinary effort which combines not only diverse technical skills (firmware, network and software development) but also user experience, design and business analysis. A proper investigation of the tasks to work on is required so as to achieve mutual agreement and, most importantly, an understanding of task allocation and ownership. We advocate that it is preferable to set short, achievable milestones rather than promising than risky ones when it comes to IoT utilisation.

Future work involves further validating our framework, optimising it for specific use-cases, exploiting cloud-based servlerless architectures and extending it to cover larger deployments.

Acknowledgments

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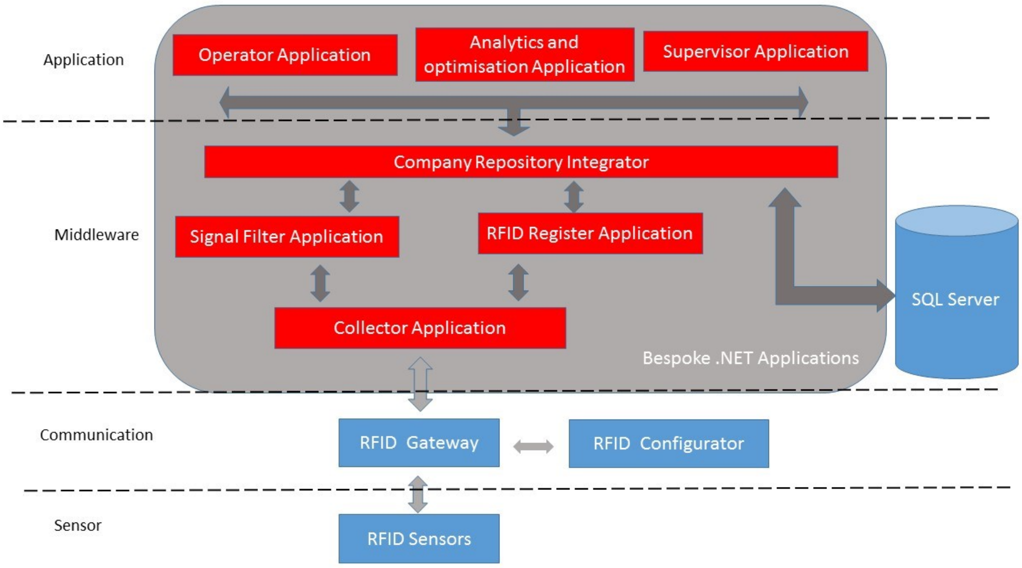

Fig. 2. Architecture for smart shelving

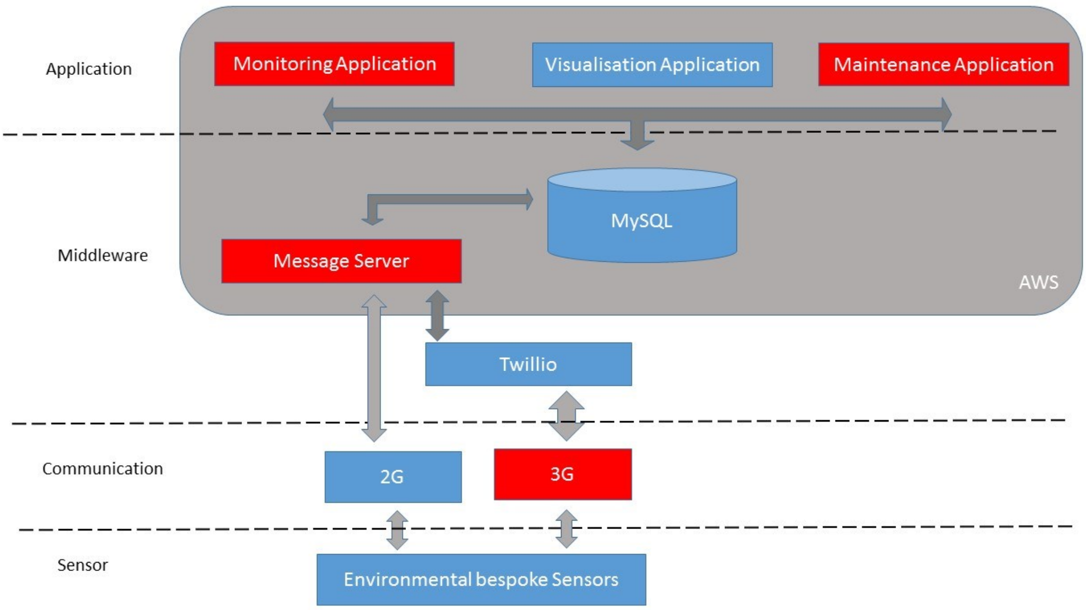

Fig. 3. Architecture for Environmental Analysis and Monitoring