Enhanced Patient Management in a Hospital Setting

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Abstract

A hospital environment must accommodate elective patients and emergency cases; this places great strain on healthcare systems. The management of patients must be at the centre of healthcare systems; to optimise patient management and resource usage the monitoring of patients, staff, and medical facilities forms a central function. Situational-awareness is introduced to provide a basis upon which effective patient monitoring and care pathway optimization may be achieved. Situation awareness requires data capture and processing in intelligent systems; we provide an overview of this with consideration of intelligent context processing and the related context processing algorithm. This paper considers the issues and challenges with the technological developments which may provide a solution to the challenges faced (or at least mitigate the impact of the challenging complex and dynamic hospital environment). Patient monitoring is introduced and the relative merits and de-merits of patient monitoring using RFID technologies are addressed with consideration of Internet based approaches including the Internet-of-Things in Cloud-based solutions. It is postulated that technology enhanced patient management based on situational awareness in intelligent context-aware systems has the capability to improve patient experience along with improvements in resource utilization in a hospital setting.

Keywords: situational awareness, hospital settings, enhanced patient monitoring, patient management, resource utilization, technological developments in health informatics, RFID, Internet solutions, cloud-based systems, cloud service models, data processing, intelligent context-aware systems.

1 Introduction

A hospital environment faces a number of challenges. Healthcare systems in a hospital setting must accommodate multiple specialisms in a broad and diverse range of departments to provide treatment to patients suffering from a similarly diverse range of conditions. Additionally, healthcare provision in a hospital setting must accommodate pre-planned and scheduled procedures (elective patients) and emergency cases which generally arrive without warning or at short notice in both small and large numbers. It also must be bourn in mind that an elective patient (who may be very ill) may due to complications become an emergency patient during the course of their treatment. In considering the challenges identified it is clear that hospital environments are characterized by consistent dynamic uncertainty; it is therefore also clear that patient management in hospital environments with the provision of effective care pathways represents a significant challenge.

The focal point of any healthcare system (particularly in a hospital setting) is the patient and the provision of an effective care pathway [30][2]. The dynamic nature of the patient profile militates against the ability of clinicians and healthcare professionals to focus on patients as the dynamic uncertainty places significant demands on hospital staff (both in clinical and administrative) time to treat patients effectively and manage the hospital facilities (e.g., X-Ray, MRI scanners, etc). To better manage patients care pathways and to optimize the use of hospital facilities there is a clear need to have knowledge

IT CoNvergence PRActice (INPRA), volume: 1, number: 3, pp. 1-21

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of a patient's current state (or context in computational terms) in 'real-time'. This knowledge must acknowledge a patient's location and current state from both a health perspective but also as it relates to their use of hospital facilities to enable clinicians and hospital administrators to revise treatment plans [as required] to accommodate the dynamic uncertainty and patient profile as it relates to the entirety of the hospital.

To mitigate the impact of the dynamic change this paper introduces the concept of Situational Awareness (SA) with intelligent context-aware systems in which (generally) sensor derived data is processed into contextual information and used to provide staff at all levels with 'real-time' information relating to patients' in terms of their 'numbers', current prevailing 'locations', and 'states'. The issues of patient management under uncertainty are considered along with the technological developments which may provide a solution to the challenges faced by healthcare professionals (or at least mitigate the impact of the challenging complex and dynamic hospital environment).

This paper is structured as follows: patient management is considered with information systems in a hospital setting. Situational awareness and entity profiling predicated on context is discussed with the application of Web 2.0 technologies and social media. We consider the technological perspective as it relates patient monitoring and informatics with consideration of a range of solutions including RFID and Internet solutions with a discussion around the Internet-of-Things (IoT) and the Cloud-of-Things (CoT). Context Processing (CP) is addressed with consideration of the Context Processing Algorithm (CPA) which provides an effective Basis upon which predictable decision support may be realised. Illustrative scenarios are presented to demonstrate the RFID approach and the alternative Internet-based approach proposed in this paper with a comparative analysis. The paper concludes with a discussion, conclusions, and open research questions. This paper postulates that technology enhanced patient management based on intelligent situational awareness has the capability to improve patient experience with improvements in resource utilization in a hospital setting.

2 Patient Management

The majority of medical procedures require a combination of both clinicians, hospital staff, and often medical facilities located is specialist departments in locations remote from the wards; thus many medical procedures relate to patients movement, location, and processing [28]. Optimising patient movements for medical procedures represents a significant challenge [36]. Where patient flows within a hospital setting are well-organized and systems are capable of adapting to changing situations healthcare practitioners' decision making and patient management can be improved [9]. SA [37][15][33] as it relates to patients, staff, and resources forms a critical role in realizing effective patient management; as such knowledge is required to enable decisions regarding a patient's care pathway to be made as the availability of staff and resources can impact the care pathways [4].

A healthcare environment not only needs human judgment for medical procedures but also for patients' administration and management throughout their treatment. If technology supports practitioners' knowledge and shares real-time decisions throughout the patients' flow then it can optimize resource management [6]. Analysis of the healthcare process, knowledge management, and technology integration within healthcare procedures is a complex task; as is the provision of 'real-time' data which can empower improved decision support and patient flows. To understand and improve these complexities healthcare procedures need analysis, categorization, and visualisation of processes at various levels [2].

The problem for healthcare is not only that: practitioners should have quick access to information in a readily accessible form (visualisation) but they should have minimum possible interaction with a system for maximum direct care time [12]. Knowledge [26], for healthcare practitioners is key to providing decision support for patient treatment pathways within healthcare; effective patient management

requires knowledge of the demands being placed on the system with the related workflows. Such knowledge assists in the alignment of resources under uncertainty [10][3]. If the solution supports healthcare knowledge by utilizing technology [in autonomic systems] there is the potential to reduce staff overhead (time spent in data collection and logging etc). Additionally, automation reduces the possible number of errors where humans can update information, wrongly.

Knowledge support in conjunction with 'real-time' intelligent context-aware systems can improve healthcare decision-making. However, There is a need for an autonomic system capable of predictable decision-support which can provide, in an appropriate and integrated manner, 'real-time' knowledge-based support in technology enhanced patient management systems incorporating SA.

3 Hospital Information Systems

Information systems in a hospital setting must address a multitude of functions including:

- The type of patient (elective, outpatient, emergency)
- The current and updated location of patients, clinicians and hospital staff with proximate information.
- Electronic patient health records with legacy systems and the patient observation records with the current state of a patient in relation to a treatment pathway / prognosis / diagnosis.
- The current state and workload of hospital systems such as X-Ray facilities, blood transfusion services, operating theatre availability, and staff and clinician availability.
- Sensor derived data obtained from patients on an ongoing basis relating to physical vital signs.

The current state-of-the-art in SA as it relates to patients and hospital staff fails to provide effective and reliable current information as the means of visualization is often a white board updated manually with the resultant latency and the resultant inaccuracies and issues in patient management. To this end visualizing the results of monitoring and processing of the data captured forms an essential function; based on the maxim "Form-Follows-Function" [7] the presentation of the data must be in a format to suit the role of the staff (e.g., clinician, nurse, hospital porter, etc) and also where required patients and family members.

An effective information system implemented using SA should be aware of: • Observations (manual and sensor driven) resulting from patient monitoring including the location of patients together with that of clinicians and hospital staff together with their availability.

- The location and availability of mobile hospital equipment including porters and general staff.
- The state and workload of hospital systems such as X-Ray and operating theatre facilities
- The impending potential work load driven by the demands of emergency patients

Such an information system may prove invaluable in improving both the quality of care and treatment of patients (elective, outpatient, and emergency) and also in the effective utilization of expensive treatment resources. Situational awareness implemented in intelligent context-aware systems as introduced in this paper provides the potential to realize this vision.

4 Situational Awareness and Entity Profiling

Situational Awareness (SA) describes a paradigm in which the location and profile (or context) of an individual is defined in a computational (and ideally human readable) formalism. However, in considering SA we must first consider the profiling of entities. We have observed that to manage patients care pathways and to optimize the use of hospital facilities there is a clear need to have knowledge of a patient's current state (or context in computational terms) in 'real-time'.

The reference to 'facilities' identifies the need to profile not only individuals (patients and staff) but also facilities (e.g. X-Ray and MRI scanning facilities). We can therefore conclude that we are dealing with 'entities'; in this context an entity has been defined in [1] as: "a person, place, or physical, or computational object".

Therefore it is clear that SA is not restricted to individuals or persons but can be applied to a broad and diverse range of people, entities, locations, and in a hospital setting a medical facility. SA as it relates to entities provide an effective basis upon which clinicians and hospital administrators can [where required] revise treatment plans to accommodate the dynamic uncertainty and patient profile as it relates to the entirety of the hospital.

4.1 Context

The first use of context in computer systems runs concurrently with the development of pervasive computing and the emergence of mobile computing components in the early 1990's. These developments have led to the desire to support computer usage in a diverse range of environments and domains [22]. Context forms an important element in pervasive computing, for example, in location-based services. This analogy clearly extends to healthcare systems predicated on SA. Implementing SA requires the creation of a profile for an entity (termed a context). In creating a context definition location is an important parameter; however, while location is important many other parameters are used to target service provision [22][23]. As such context in general and in hospital settings is highly dynamic and inherently complex.

Context is central in realizing SA, context describing a prevailing dynamic state, as such it is inherently complex and domain specific [24]. A context is created using contextual information (context properties) that combine to describe an individual or entity, therefore a broad and diverse range of contextual information combines to form a context definition [21]. In actuality, almost any information available at the time of an individual's interaction with a context-aware system can be viewed as contextual information [21] including:

- The variable tasks demanded by users with their preferences, and constraints.
- The diverse range of mobile devices and the associated service infrastructure(s) and availability.
- The physical (environmental) situation (temperature, air quality, light, and noise level etc).
- The social situation (who you are with, people nearby - proximate information)
- Spatio-Temporal information including orientation, speed and acceleration.
- Physiological measurements: blood pressure, heart function (ECG), (EEG), respiration, galvanic skin response (GSR), and motor functions.
- Cognitive information such as an individual's emotional responses. This includes Electromyography (EMG) which records the electrical activity produced by skeletal muscles [21][14].

The potential contextual information identified demonstrates the diverse nature and inherent complexity of context and context-aware systems. The list of potential context properties includes cognitive properties; these are relevant and significant in a range of conditions such as depression and Alzheimer type conditions. A discussion on these conditions is beyond the scope of this paper however a discussion on the topic can be found in [21].

4.2 Situational Awareness and Social Media

An interesting concept in relation to situational awareness [37][15][33]is the use of "people-as-sensors"; this may be viewed in terms of "crowd-sourcing". SA has been explored in [37][15][33] where social media has been investigated in relation to local community SA during emergency situations such as a multi-vehicle motorway accident with multiple trauma casualties.

Central to the implementation of SA is the identification, capture of data and it's processing to derive interesting information useful to clinicians, healthcare professionals, and managers in a hospital setting. This activity requires sensors and a communications network. As alluded to above, people and social media (Twitter, Facebook, etc), may provide a means by which advance notification of an impending or actual emergency situations may be identified [37][15][33]. The following section considers the challenges in identifying suitable sensors and sensor networks. Typical scenarios in which technology enhanced SA can assist in improving patient management in a hospital setting are set out in section VII.

5 Technological Considerations and Health Informatics

We have considered SA and context; health informatics however encompasses a number of elements and functions including: approaches to patient monitoring and technological consideration as they relate to sensor networks employed in entity monitoring. The following sections consider these aspects with an introduction to Cloud systems and service models use in Internet and Cloud-based solutions.

5.1 Patient Monitoring

Traditionally, patient monitoring has primarily been conducted using human observations (generally by nursing staff) with paper-based records. Sensor technologies have been employed however their usage has generally been restricted to invasive (physical) sensors in for example an intensive care unit (ICU) for post-operative and critical patients.

In considering patient monitoring and management location is vitally important; this has not however been a significant feature of patient monitoring in a hospital setting. There are technologies in use including 'intelligent' or 'smart' white boards; these are manufactured by many health informatics organizations however the intelligence incorporated into the white boards is very limited being restricted to, for example, a nurse 'dragging' an icon from one location to another as a patient moves from, e.g., a ward to an X-Ray facility. This approach employs technology which is ineffective and error prone (human error) and visibility (restricted generally to one location generally in the ward the patient is resident). As we discuss in the following section RFID technologies have been employed in patient tracking however the use of such approaches has not been translated into an automated process with locations updated and presented visually on e.g., a 'smart' whiteboard.

5.2 Sensor Technologies in a Hospital Setting

There has been a significant body of research addressing information systems in a hospital setting; see for example: [28][36][9][6][2][12][26][10][3][4][8][27][30][20] and [16] which addresses RFID tech-

nologies (see the discussion in later sections). The research identified if not comprehensive however it demonstrates: (1) the range of the documented research, and (2) the fact that the research is largely domain (i.e., a particular hospital setting) specific and in general addresses modalities as they relate to information systems and patient management.

Sensors in hospital settings include highly sophisticated visual processing, chemical-component discrimination, pain detection and diagnosis features, together with adaptive intelligence [35]. However, usage of technology adopted by clinicians in patient care must include appropriate contextualised visualisation to optimise the use of time, provide the information in a format that aids accurate patient assessment, and may even augment their intuition, senses, and abilities. Examples of such technologies include: (1) X-Ray machines, (2) MRI body scanners, and (3) scheduling software.

Figure 1: Accessing data using a tablet computer, RFID and barcodes.

Currently, a significant technology associated with them is the Smart Phone or more generally Tablets; such tablets are generally not commercially available devices (e.g., Apple or Samsung etc) but are specifically designed and built by health informatics organisations with specialist software to suit a hospital setting. Many can be interfaced to RFID and NFC terminals allowing for 'on-the-spot' use. For instance, Figure 1 shows an Android enabled tablet being used with RFID and barcodes for access to sensor data (left of image) and e-Health information (right of image).

Given the developments in and the prevalence of sensing and communication technologies it can be expected such technologies will gain traction and cause a revolution in patient monitoring and management. As discussed in [4] adoption of health-information technologies is a significant driver in the costs associated with healthcare, although that must be balanced against potential to ensure high levels of patient satisfaction commensurate with their care [10][4][30].

In this paper the focus is largely on the technological aspects of patient management and monitoring using the 'next-generation' of systems devoted to patient monitoring and record keeping in autonomic and semi-autonomic systems based around Internet-based solutions. In this section we initially we consider RFID approaches followed by a discussion around IoT, CoT, and Cloud-based systems with service models that operate in a Cloud environment.

A current trend in RFID is use of higher frequencies which are being utilised for parallel-location of many tags to within a few hundred millimeters, which may allow simple and cost-effective tracking of patients, clinicians and equipment in future healthcare. Similarly, many other sensors exist that could show significant benefit, including patient-mounted ECG, EEG, GSR, light and temperature measurements, including within body-area networks. Such devices are also simply interfaced to computer-networks and mobile devices, allowing enhanced integration into the Internet-of-Things and the Web-of-Things.

One example of a pervasive technology in healthcare is Radio-Frequency Identification (RFID) and

the related Near-Field-Communications (NFC). Currently being used in a wide range of scenarios including: patient-tagging (for recording and location), prevention of drug-counterfeiting, and personnel-identification [10][2]; it is also deeply implicated in the Internet-of-Things and, as with most sensors, can play a part in the Web-of-Things which aims to increase integration of the World-Wide-Web with real life objects (e.g. through RESTful interfaces). As with other areas of life, those two concepts can be expected to form the backbone of future e-Health informatics.

5.3 RFID Systems

The IoT concept incorporates/encapsulates the ubiquitous devices around us, ranging from small embedded systems such as Raspberry Pi to tiny sensor devices (including smart dust sensors)[33] in the home, on the human body or in a vehicle. These devices being connected through a variety of media formats, more specifically in the healthcare sector, these IoT devices, will invariably be connected wirelessly [12][18].

In healthcare the backbone will be Internet Protocol (IP) based devices wirelessly connected communicating and transmitting real time data to local access points that are connected to cloud services. Dependent on device, there will be variable amounts of on-chip sensing, processing and data transmission. Automatic data collection is the preferred method as there is less opportunity to introduce errors. Take for example (still in operation today) where a white board has a multitude of patient information, there will be at some stage transcription and interpretation errors, some minor some major. The system should try and capture at source and keep human intervention to a minimum.

Current RFID technology has constraints [4], these are primarily based on proximity, for those devices that do not have power, i.e. passive RFID tags. Size for those RFID tags that have power and also interoperability between RFID devices, due to varying interpretations of the communications protocols from different manufactures [2]. The work carried in [4] and their proposal to augment RFID and use Bluetooth to communicate the sensory data has proved successful, the major advances were leveraged by the use of cloud technologies for data collection, manipulation and visualisation.

Although possibly more expensive, this papers proposes to go further and directly use the latest Bluetooth and Wi-Fi based sensors for data collection and identification. As Bluetooth is localised, this tends not to interfere with healthcare equipment and the reason for WiFi that is the prominent pervading wireless technology in most buildings including the health sector. The intention of this research is to use cloud technologies to store, manipulate and visualise, but also to schedule real time requirements, specifically in an emergency situation when flexible computing resources are needed [2].

5.4 Internet Solutions

Recent developments in Cloud-Based-Systems (CBS) have resulted in what has been termed: the Internet-of-Things (IoT) which in a medical context has been referred to as: the 'Internet-of-Health' (IoH) [34]. There is a close affinity affinity between the IoT and Cloud-based systems (CbS); in actuality in modern contexts the IoT may be more correctly referred to as the Cloud-of-Things (CoT) [34].

There is a large body of research around cloud-based systems and the health sector has an abundance of services that could be serviced by the cloud; there is however a great deal of scrutiny as to the suitability of cloud services for use in the health sector. In actuality the term "Cloud" has no clear and commonly agreed definition; there is a large body of documented research in which a definition for the term: "***Cloud***" has been considered and it has been suggested by Wyld [38] that the term "***Cloud***" be viewed as an acronym standing for: "*Common, Location-Independent, Online, Utility that is available on Demand*".

If we dissect this acronym, it is relevant to the offering today, there are Common services, i.e. shared with individuals and companies; we do not generally know where these services are unless we ask suppliers for the location, so services can geographically dispersed and user generally do not care, i.e. Location independent; these services are generally web based and so Online; finally the demand is elastic and we can use as little or as much dependent on requirements and SLA's, therefore available on-Demand. As with utility services, Cloud solutions are usually auto configuration and reconfiguration on the fly, based on agreed SLAs, with properties such as auto monitoring, fault recovery and healing, to provide high resilience and minimum outage times [34].

These definitions are exactly the kinds of services that are required for enhanced patient management. We need the common data, presentation and equipment available to all Health Care Professionals (HCP). A similar visualization is required for all the users, consumers, practitioners and in limited capacity the patient (subject to access rights, permissions, and protocols) as the geospatial location of staff will not be generally known to the system. The services need to be available on any device, anytime and anywhere by the various HCP, dependent on requirements as one day it may be an emergency and on another day it may be an outpatient, i.e. the system must enable Situational Awareness to deliver the service. Finally when there is an unpredictable event or major crisis, these services may be needed a lot more than normal hence are required to be available on demand, just like more electricity and gas is used in cold weather. This is one of the reasons that cloud services are referred to as a Utility [38][32].

5.5 Cloud-Based Solutions and the Health Sector

There is generally an element of confusion around the concept of the 'Cloud'; there being no generally agreed definition of the term. In asking: "What is Cloud computing?" Hartig in [13] observes: "the cloud is a virtualisation of resources that maintains itself". This definition, while adequate in a general sense fails to capture the complexities that characterise Cloud-based solutions. In relation to the medical context an interesting discussion on: "ubiquitous access to cloud emergency services "can be found in [18]. Ubiquitous access *on-demand* and *anytime-anywhere* (within the provisions of location and access rights and permissions) is an essential requirement in the health domain and Cloud-based solutions offer this service.

As we have discussed context and SA encompasses much more than location; this aspect of SA however remains a pivotal component in context-aware patient management; Morton *et al* in [25] address this in respect of "location and activity tracking in the cloud". The IoT and sensing of entities is, as we have discussed, central to enhancing patient management; Rao *et al* [29] consider these elements in a paper entitled: "Cloud Computing for the Internet of Things & Sensing-Based Applications. While the work of Rao is not patient management focused their work has a clear relationship to patient management and the sensing of entities (as we have discussed) in a hospital setting.

Mazhelis *et al* in [19] investigate the: "Impact of Storage Acquisition Intervals on the Cost-Efficiency of the Private vs. Public Storage"; this forms a strategic decision both in the option to use a Cloud-based solution (as opposed to a traditional in-house approach) and also in the cloud system to be adopted. There are generally 3 cloud system types in common usage:

1. a *Public clouds*
2. a *Private clouds*
3. a *Hybrid clouds*

Figure 2 graphically models the 3 cloud system types and the relationship between them. Of potential interest from a healthcare perspective is the *Hybrid Cloud* which, as we discuss below, may address the

privacy and security concerns while leveraging the power of cloud-based solutions where, for example, *Software-as-a-Service* may provide for efficiencies in technology and system management.

5.5.1 Public Clouds

A cloud is called a 'Public cloud' when the services are rendered over a network that is open for public use. Technically there is no difference between public and private cloud architecture, however, security consideration may be substantially different for services (applications, storage, and other resources) that are made available by a service provider for a public audience and when communication is effected over a non-trusted network. Generally, public cloud service providers such as Amazon, Microsoft and Google own and operate the infrastructure and offer access only via Internet.

A Public cloud refers to offsite, multi-shared occupancy of hardware services, hence providing optimum efficiency of use. Because of the shared nature of the services, these they are more susceptible to issues than Private cloud, as there are a limited set of control measures that can be applied. A Public cloud is best suited for large number of users for the deployment of standard issue software or Software as a Service application with a well implemented security strategy [32].

This is the most relevant to our case as we have a large number of HCP that require the same application, data and interface. This will help provide a good service that can be expanded and contracted as needed and will be welcomed by IT departments. A Public cloud pushes the responsibilities to a third party and there is a perceived lack of control and this is why HCP are concerned with the security aspects around patient data. A Public cloud also provides other opportunities that not relevant to this paper, for a detailed exposition see [29] however in summary there are contractual, legal, regulatory, and security issues which must be addressed including:

- The requirement to develop, test, and validate application code.
- The Software-as-a-service (SaaS) provider must implement a robust and reliable security strategy
- The service must be incrementally scalable to meet peak demand (in a hospital setting this is generally uncertain both in time and scale)
- There must be the capability to support collaborative projects and activities

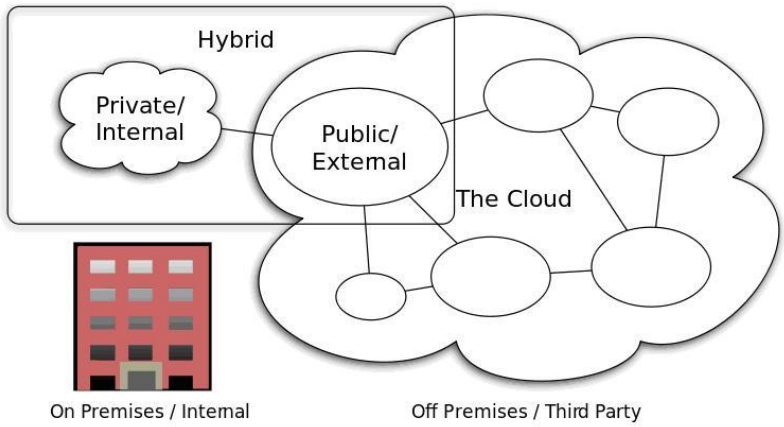

Figure 2: Cloud System Types.

In addition to these items the support for ad-hoc software development project using a Platform as a Service (PaaS) offering cloud. In the PaaS model, cloud providers deliver a computing platform, typically including operating system, programming language execution environment, database, and web server. Application developers can develop and run their software solutions on a cloud platform without the cost and complexity of buying and managing the underlying hardware and software layers. With some PaaS offers, the underlying computer and storage resources scale automatically to match application demand so that the cloud user does not have to allocate resources manually.

5.5.2 Private Clouds

A Private cloud refers to a company's investment into capital, revenue and staffing, with local staff providing all aspects of support. Therefore rendering this solution is generally more secure as there is direct control over all facets of the operation. This is an expensive option primarily due to the CAPEX, on-going replacement of equipment and the larger revenue costs of staff (OPEX).

It is generally recognised that private IT provision is not efficiently used however a Private Cloud is possibly the best option as it is best suited for meeting legislative benchmarks or data protection regulation. Health informatics is characterized by "mission-critical" functionality and a Private Cloud can be the best choice when data is the critical component of the system. This seems the ideal choice for the patient management systems discussed in this paper as HCP are focused on patient records. If the health service can afford this option, it could meet the legislative needs and met regulatory body approval.

Private cloud is cloud infrastructure operated solely for a single organization, whether managed internally or by a third-party and hosted internally or externally. Undertaking a private cloud project requires a significant level and degree of engagement to virtualize the business environment, and requires the organization to reevaluate decisions about existing resources. When done right, it can improve business, but every step in the project raises security issues that must be addressed to prevent serious vulnerabilities. They have attracted criticism because users "still have to buy, build, and manage them" and thus do not benefit from less hands-on management, essentially "[lacking] the economic model that makes cloud computing such an intriguing concept".

5.5.3 Hybrid Clouds

A Hybrid cloud is a composition of two or more clouds (private, community or public) [32] that remain unique entities but are bound together, offering the benefits of multiple deployment models. Such composition expands deployment options for cloud services, allowing IT organizations to use public cloud computing resources to meet temporary needs. This capability enables hybrid clouds to employ cloud bursting for scaling across clouds. Cloud bursting is an application deployment model in which an application runs in a private cloud or data center and "bursts" to a public cloud when the demand for computing capacity increases. A primary advantage of cloud bursting and a hybrid cloud model is that an organization only pays for extra compute resources when they are needed. Cloud bursting enables data centers to create an in-house IT infrastructure that supports average workloads, and use cloud resources from public or private clouds, during spikes in processing demands.

By utilizing "hybrid cloud" architecture, companies and individuals are able to obtain degrees of fault tolerance combined with locally immediate usability without dependency on internet connectivity. Hybrid cloud architecture requires both on-site resources and off-site (remote) server-based cloud infrastructure. Hybrid clouds may lack the security and certainty of in-house applications however the corollary is that a Hybrid cloud provides the flexibility fault tolerance and scalability of a Public cloud

with enhanced control over security which is a characteristic of in house applications. Figure 3 graphically models the principal service models.

5.6 A Comparative Analysis

In considering the Cloud solution option a comparison between Public and Private Clouds each has positive and negative aspects. Table 1 summarises these. The tabular comarison identifies the differing functional properties that characterise *Public* and *Private* clouds; it would be wrong to talk about positve and negative characteristics; the correct interpretation related to each characteristic must be related to the domain of interest. A brief overview of each characteristic is as follows:

- The *initial cost* comparison is clear however this may not be the overiding factor in the selection of a cloud type, the other factors arguably have greater prominance.
- As for the *initial cost* the *Running Cost* is domain specific and will be influenced by the capabilities realised based on the remaining factors.
- *Customisation* will be central to a users requirements specification. Where customisation forms a central plank in the requirements (as in the case of the healthcare domain) a *Public* Cloud is arguably not an optimal option. A *Private* Cloud would offer the facility to tailor the service to suit the domain specific requirements of a hospital domain.
- As for *Customisation*, a *Public* Cloud fails where *Privacy* is concerned (a host has access to the data). This is pivotal where *security*, *privacy*, *legal*, and *regulatory* requirements are concerned. A *Private* Cloud may offer the facility (in a hospital setting) to implement the security requirements with clearly defined access rights and permissions based on defined roles (clinicians, nursing staff, auxiliary and management staff).
- Compliance with regulatory regimes (data protection statutes etc) and implementing security (principally data security) while problematic for a *Public* Cloud is manageable for *Private* Clouds.
- The capability to implement a *Single Sign On* is, as for other characteristics, domain specific and may be a useful function or alternatively a security risk.
- *Scalability* is crucial in a hospital domain where the dynamic nature of the environment demands scalability both in the immediate demands but also over time. In a *Public* Cloud solution scaling up is relatively easy while within defined limits however in a *Private* Cloud solution scaling up is more laborious and may entail significant infrastructure investment in terms of hardware, software, and human cost; the scope to scale up is however potentially limitless.

This brief overview in the context of healthcare informatics implemented in a hospital setting must be considered in the light of the clearly defined need for legal and regulatory compliance plus privacy. Security, and clearly defined domain-specific access rights and permissions with visualization geared to suit the role of the healthcare professional, clinician, or patient also forms a central plank in the decision process.

Each option has its advantages and negative characteristics and while the *Private* Cloud meets the privacy, security, and access conditions it may fail in terms of scalability. A *Public* Cloud, while scalable, fails where security and privacy is concerned. A primary function in a hospital setting is the sharing of patient records between clinicians and outside organizations within the NHS; in this area a *Public* Cloud offers many advantages however the security and privacy issues probably outweigh these advantages.

Caracteristics	Public Cloud	Private Cloud
Initial Cost	Low	High
Running Cost	Variable	Variable
Customisation	No	Yes
Privacy	No	Yes
Security	Problematic	Manageable
Regulation	Problematic	Manageable
Single Sign On	No	Yes
Scalability	Simple	Difficult

Table 1: A comparison between Public and Private Clouds

In summary it is clear that neither cloud type alone fulfills the demands of health informatics. In Section 5.5.3 we consider a third option, a *Hybrid* Cloud solution (see Figure 2) which may offer the potential to meet the identified conditions and demands.

6 Cloud-Based Service Models

Within the Internet and cloud service provision there are generally 3 service models in use:

1. Infrastructure-as-a-Service (*IaaS*)

2. Platform-as-a-Service (*PaaS*)

3. Software-as-a-Service (*SaaS*)

The 3 service models are briefly discussed in the following sections; Figure 3 represents graphically these service models, shown is the layered approach with: *infrastructure*, *platform*, and *application* layers. In addition to the 3 service models identified there is also a service model termed Network-as-a-Service (*NaaS*); an overview of this service model is set out below.

6.1 Infrastructure-as-a-Service

Possibly the most basic cloud-service model is the *Infrastructure-as-a-Service* (IaaS) model. The IaaS model generally encompases provision of computing facilities; two general approaches exist: (1) physical hardware, and (2) virtual machines.

Pools of hypervisors within the cloud operational support-system can support large numbers of virtual machines and the ability to scale services to suit user requirements. IaaS clouds often offer additional resources such as a virtual-machine disk image library, raw (block) and file-based storage, firewalls, load balancers, IP addresses, virtual local area networks and software bundles; IaaS-cloud providers supply these resources on-demand from data centers. Connectivity is realised using the Internet or 'carrier clouds' (dedicated virtual private networks).

To deploy applications, users install operating-system images and their application software on the cloud infrastructure. In this model, the cloud user patches and maintains the operating systems and the application software. Cloud providers typically bill IaaS services on a utility computing basis: cost reflects the amount of resources allocated and consumed.

6.2 Platform-as-a-Service

In the *Platform-as-a-Service* (PaaS) model cloud providers deliver a computing platform which typically includes the operating system software, programming language execution environment, database, and web server. Developers are able to build and operate software solutions in a 'Cloud' environment without the expense (financial and time) and complexity of purchasing and managing the underlying hardware and software layers. PaaS may additionally offer the potential for the underlying computer and storage resources to scale automatically to meet the demands of application(s) which avoids manual resource allocation and the resultant time and expense incurred.

6.3 Software-as-a-Service

The term *Software-as-a-Service* (SaaS) is considered to be part of the nomenclature of cloud computing along with IaaS, and PaaS. There are also a number of service models including: *Desktop-as-a-Service* (DaaS), *Backend-as-a-Service* (BaaS), *Information-Technology-Management-as-a-Service* (IT-MaaS), and in the future possibly *Data-as-a-Service* (DataaaS) which may provide sophisticated data analytics and data mining in 'big-data' solutions. SaaS is also referred to as "on-demand software" and is generally supplied by ISVs or *Application-Service-Providers* (ASPs). SaaS is software delivery model in which software and associated data are centrally hosted on the Cloud. SaaS is typically accessed using a thin client or a web browser.

SaaS has become a relatively ubiquitous delivery model for many business applications, including from a healthcare perspective:

- Management information systems (MIS), accounting software, customer relationship management (CRM) systems, enterprise resource planning (ERP) systems, human resource management (HRM) systems, and service desk management systems
- Office and Messaging software
- Database management systems

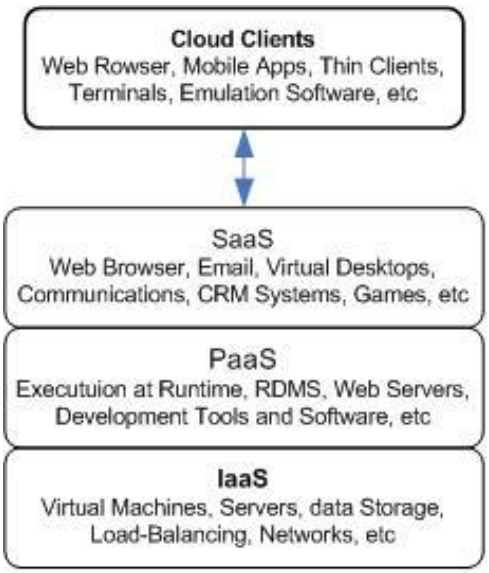

Figure 3: Service models.

- Visualisation (information representation, see Figure 1 for an example using a Tablet) and related analytic applications

SaaS has been incorporated into the strategy of many leading enterprise software companies; one of the principal benefits being the potential to reduce IT support costs by outsourcing [hardware and software] maintenance and support. SaaS provides users with access to, for example, application software and database systems with the management functions in respect of the infrastructure and platforms being provided by the SaaS provider.

SaaS may be viewed in terms of a 'utility' as is may be accessed 'on-demand' on a 'pay-per-use' basis. Additionally, SaaS provides users with a central hosting model in which updates can be released without the need for users to install new software. One drawback of SaaS is that the users' data are stored on the cloud provider's server. As a result, there could be unauthorized access to the data (we discuss this potential issue with other issues below).

Cloud-based solutions differ from 'in-house' IT solutions in that scalability can be realised. This is achieved by cloning tasks onto multiple virtual machines at run-time to meet changing work demand. Load balancers distribute the work over the set of virtual machines. This process is transparent to the cloud user, who sees only a single access point. To accommodate a large number of cloud users, cloud applications can be multi-tenant (e.g., any machine serves more than one cloud user organization).

6.4 Network-as-a-Service

As noted there is a fourth service model, the *Network-as-a-Service* (NaaS). Space precludes a detailed exposition on this service model however in summary: it is a category of cloud services where the capability provided to the cloud service user is to use network/transport connectivity services and/or inter-cloud network connectivity services. NaaS involves the optimization of resource allocations by considering network and computing resources using a holistic approach. Traditional NaaS services include flexible and extended VPN, and bandwidth on demand. NaaS concept materialization also includes the provision of a virtual network service by the owners of the network infrastructure to a third party.

7 Patient Monitoring in the Cloud

A central function in effective patient monitoring and management is the personalization of service provision (the care pathway) based on their current prevailing state. The IoT (in a medical context the IoH) in capturing sensor-derived data and processing it into information useful to clinicians and healthcare professionals provides a basis upon which effective personalised healthcare can be provided while optimising the use of hospital resources and facilities.

The revolution in smart-phone technologies along with their ubiquity has provided opportunities to inform behaviour and prompt interventions where required at an appropriate level; see [14] for healthcare examples. In the case of the iPhone, it has even been used for microscopy and spectral-analysis of blood and tissue samples [12] using very simple adaptors. Similarly, GPS is widely used in the health-sector, such as locating emergency vehicles and personnel, and has potential for locating patient's en-route to hospital, for advance scheduling, via their phones. Accelerometers and gyroscopic sensors are a particularly exciting aspect of mobile devices, allowing simple testing to aid diagnosis, especially when combined with knowledge-bases about conditions and symptoms. Mobile phones and tablets are also able to interface with medical equipment over wired (e.g. USB and RS232) and wireless (e.g. Bluetooth and Wi-Fi) connections, including through the cloud. Therefore, they have the potential for revolutionising access to medical data, sensor data and expert systems, greatly augmenting the abilities

of clinicians and carers. For patients and clinicians alike, they also have the potential for quick and simple scheduling input, and communication of needs and even emotions.

Additionally, the integration of the CoT with smart-phone technologies opens up many interesting areas related to the sensing of behaviour(s). For example, Figure 2 shows RFID tags (compatible with Near-Field-Communication (NFC) devices; such devices can be written to and read by a wide range of smart phones and tablets. Also shown is an inexpensive RFID reader that can be use with tags built into a range of equipment including: furniture, consumer goods, and other artifacts. In fact the RFID reader can be incorporated into clothing to implement wearable sensor systems. The sensor modules shown in Figure 4 include examples of inexpensive temperature, humidity, acceleration, rotation, and red-green-blue (RGB) light measurements. Many other inexpensive sensors are similarly available and Easily Internet connected for mobile device interfacing.

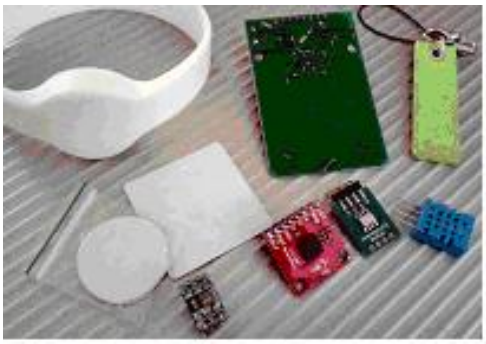

Figure 4: Figure 4. Sensors, RFID tags and an RFID reader.

The applicability of such RFID technologies has a clear application in a hospital setting where a range of uses can be envisaged including: smart clothing (for staff and patients), equipment, facilities, wheelchairs, and trolleys etc. Many other technologies also exist for inclusion in an *Internet-of-Health* (IoH). A discussion on the IoH is beyond the scope of this paper however wireless patient and healthcare-professional location (simply achieved through received-signal strength data in, for example, Bluetooth and Wi-Fi, and for more localised use via ZigBee enabled sensor) should be noted [10]. Also, devices such as the Microsoft Kinect have shown themselves capable of useful 3D positioning over short distances and also have applications within interactive recuperation software.

8 Data Processing

This section addresses the processing of data (*contextual information*) in intelligent context-aware systems for approaches predicated on SA. The processing of contextual information requires the implementation of data fusion however this concept fails to realise intelligent processing of data that identifies situational awareness and the related contextual information. As discussed in section 4 and sub-section4.1 a broad and diverse range of information can be viewed as contextual information. Indeed, if data can be captured, codified, and processed it can be viewed as contextual information.

Central in the proposed approach to context processing is the context processing algorithm (CPA) provides a basis upon which contextual information can be processed in an intelligent context-aware system that enables constraint satisfaction (CS) with predictable decision support (an essential property in any health related application) [23][24][21].

8.1 The Context-Matching Algorithm

The CPA approach is predicated on the processing of contextual information using the CM process [24]; CM (an extension of the data fusion concept) is designed to create the input context and access the output context(s) definitions to determine if the output (solution) context is an acceptable match with the input (problem) context. Essentially, the context-matching process is one of reaching a Boolean decision as to the suitability of a specific individual based on context [24]. Given that a perfect match is highly unlikely the CM algorithm must accommodate the PM issue along with a number of related issues as discussed in [24]. In CM the probability of a perfect match is remote therefore partial matching (PM) must be accommodated.

To address the PM issue the CPA applies the principles identified in fuzzy sets with a defined membership function which is predicated of the use of decision boundary(s) (thresholds) as discussed in [24]. The membership function provides an effective basis upon which predictable decision support can be realized using both single and multiple thresholds to increase the granularity of the autonomous decision making process.

For a detailed exploration of fuzzy sets and fuzzy logic see [17], a comprehensive discussion on fuzzy rule-based system design principles can be found in [5]. In summary, Fuzzy Rule Based Systems have been shown to provide the ability to arrive at decisions under uncertainty with high levels of predictability [24]. A discussion on the CPA and rule strategies with the related conditional relationships for intelligent context-aware systems with example implementations and a dataset evaluation see [23][24][21].

9 An Illustrative scenario

We have discussed SA as it relates to patient monitoring and management with of the technological aspects and approaches to implementation. To illustrate SA we now consider an illustrative scenario where sensor-based patient monitoring is applied in a Cloud-based information system for a hospital setting.

9.1 Patient Management Scenario

Consider an all too real typical situation involving the management of patients scheduled for elective treatments, tests, and surgery where the influx of outpatients and spontaneous emergency patients (possibly the result of a major incident) places great strain on clinician, hospital staff, and managers due to the uncertainty generated by these dynamic situations. In a typical large general hospital setting there are multiple departments with elective patients, outpatients, and emergency patients. In such settings the patient profile (both in terms of individual patients and the patient population) is highly dynamic and is subject to high levels of uncertainty.

In emergency situations the planned (elective) procedures are impacted by the influx of outpatients and emergency patients. In such situations patient management may be considerably improved by SA related to patients, clinicians, hospital staff, and facilities [such as X-Ray and MRI scanners], and operating theatre availability. The following scenario models technologically enhanced SA with intelligent processing as it relates to patient management and the treatment pathways for differing classifications of patient. In this scenario there are varying levels of severity with the requisite time critical treatment demands. The actors in the scenario are:

- ‘Bob’ has been admitted for a planned and elective routine surgical procedure. The treatment pathway requires a pre-operative examination by a consultant clinician with a range of tests and blood transfusion.

- 'Anne' is a day patient admitted for scheduled diagnostic tests which are: X-Ray, MRI scan, and examination by a consultant clinician.
- There is a major incident with multiple trauma casualties varying from minor to life threatening which require emergency on-scene paramedic treatment and follow-up treatment in the hospital setting.

The treatment pathways for 'Bob' and 'Anne' are scheduled with the X-ray and MRI scanning facilities booked and the consultant clinicians and their staff are prepared for the planned procedures. The ambulance service receives emergency calls related to a major incident with multiple trauma casualties. Simultaneously exceptional social media activity is noted related to the scene of the incident. Initial reports from the paramedics attending the incident are sent to the hospital with potential trauma conditions; the social media providing additional information which, whilst non-specific may inform the scheduling of hospital staff and resources. SA has the ability to identify the scheduling and workload of the X-Ray and MRI facilities along with the workload and availability of the operating theatre and staff and provides the knowledge to enable the re-scheduling of care pathways (for patient's), workload of clinicians and staff, and the re-scheduling of hospital facilities such as an X-Ray department. Thus in the event of an emergency requiring for eaxmple an X-Ray an elective patient awaiting an X-Ray may be diverted to for example an MRI facility.

9.1.1 Technical Considerations

In considering the technical aspects related to the implementation of SA for the scenario to optimise the effectiveness of the patient management SA must have knowlege of:

- Available mobile devices and their context (i.e., location, state, etc)
- The current state and workload of hospital facilities (i.e., X-Ray etc)
- Patient location and context including planned movements / treatments etc
- Clinicial, healtcare, and auxiliary staff context
- A general patient profile and system loading information including expected emergency patients

Addressing these requirements will utilise RFID and Wi-Fi enabled devices (the IoT) in a Cloud-based system. In such a system the location and current prevailing state of patients, staff, and facilities will be known and dynamically updated using where required triangulation techniqies to identify a current location. In such a system visualisation of the data forms a crucial element; this must show in a readily accessible form test results, bed availability, staff availability, location, and proximity information to enable scheduling software to manage patient care and treatment.

In order to accurately track patients, they will be tagged on arrival with Wi-Fi enabled 'smart sensors' [the installed network infrastructure provides secure communication] containing their patient details. This provides provides the ability to locate and identify patients to ensure the correct medical attention is given as the staff will be able to see on a graphic display patient details including the history of drugs administered en-route and patients condition. This clearly identified the need for comprehensive interconnection (no one device is independent) via the cloud and all the data must be communicated securely through VPN networks. It is possible that more local data storage could added using passive RFID tags on a patient or the bed. There is also in the future the potential for sensors to incorporate primary data storage and processing [using for example a simple computer such as the Raspberry Pi [11]. For a a discussion on sensor technologies, smart care space, the IoT, and the CoT see [35][34].

We now have the tagged patient, the tagged bed and tagged equipment needed for the trauma patient to be treated. Next we need to locate the clinician, most staff a have mobile phone, hence this could be their position locator, for example 'Smart-Phones' can be located very quickly to determine their location. Alternatively, WiFi enabled smart sensors can be given to clinicians and staff. Independent of the device, the system can locate an available clinician along with the required staff (the current state and workload of hospital facilities will be known to the system) and for a patient in the A & E department schedule the treatment and the required resources. At each stage the system can be auto updated to postpone and re-schedule patients treatments. Also the system will be capable of monitoring entities (including e.g., 'Bob' and 'Anne') based on the dynamically changing patient profile at any prevailing time.

9.2 Analysis

The brief illustrative scenarios demonstrate the inherent dynamic uncertainty that characterizes hospital settings and additionally introduces the concept of SA as a means to improve the effectiveness of patient management in a hospital setting. SA in the scenario enables identification of the current prevailing state of entities (patients, hospital staff, and importantly the facilities along with their workload / availability). This allows for dynamic 'on-the-fly' re-scheduling of treatments to maximize the use of hospital facilities and resources while mitigating the impact on 'Bob' and 'Anne'. Thus, SA in a hospital setting has the potential to improve: (1) patient management, (2) the patient experience and the QoL, and (3) the efficient and effective usage of [generally very expensive] hospital facilities.

From a technical perspective IoT devices [35][34][29] connected and communicating wirelessly across any geographic area represents a Cloud-based solution; thus the application of SA has the potential to improve: (1) treatment pathways, (2) the patient experience, and (3) the efficient and effective usage of [generally very expensive in both capital and human terms] hospital facilities.

SA (enhanced context-awareness) holds promise for improving the utility of software products. Context-aware mobile systems encompass the ability to automatically discover and react to changes in an environment [31]. SA can be viewed as an extension of context and context-aware systems. Therefore it can be seen that SA facilitated by sensor-based monitoring systems confers benefits for patients and carers in improved QoL) and for hospitals in terms of improved staff and resource utilisation, patient care, and financial efficiencies.

The highly dynamic and uncertainty implicit in the new situation requires the re-scheduling of the workload for both facilities and staff to cope with the treatment of the emergency patients whilst mitigating the disruptive impact on 'Bob' and 'Ann'. The application of intelligent SA has the potential to monitor in 'real-time' the current prevailing 'state' of both hospital facilities (including ancillary activities such as patient transport etc) along with staff location, expertise, and availability. There are therefore clear benefits for all stakeholders in a hospital setting.

10 Conclusions

This paper has addressed the issues and challenges inherent in the highly dynamic environment that characterises hospital settings which operate under uncertainty driven by the rapidly changing patient profile. In considering the challenges the use of SA as an aid to effective patient management has been introduced with consideration of the potential technologies that may be employed. Illustrative scenarios have been presented to show how the posited approach may be used in 'real-world' situations.

This paper postulates that SA enabled technology enhanced patient management based on intelligent data processing with appropriate visualization where *form-follows-function* has the potential capability

to improve patient experience with improvements in resource utilization in a hospital setting. The discussion relating to the technologies available have shown that the hardware components in a sensor-based health monitoring systems have largely been overcome (with the exception of the development of non-invasive sensors); the issues lie less in the technology and visualisation aspects [which are generally well developed and understood] than in the identification of the data required and the processing of such data in 'real-time' in patient and facilities monitoring. Implementing and validating the vision presented in this paper together with validation and the successful integration of technologies with intelligent data processing including 'Big Data' solutions remains an open research question.

There are clearly ethical issues (e.g., informed consent) where health related technologies are considered however there are potential benefits for patients (in terms of improved treatment care pathways) and for health services (in efficiencies in staff and resource usage) if effective patient management as discussed in this paper can be realized.

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