Optical fibre multi-parameter sensing with secure cloud based signal capture and processing

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ABSTRACT

Recent advancements in cloud computing technologies in the context of optical and optical fibre based systems are reported. The proliferation of real time and multi-channel based sensor systems represents significant growth in data volume. This coupled with a growing need for security presents many challenges and presents a huge opportunity for an evolutionary step in the widespread application of these sensing technologies. A tiered infrastructural system approach is adopted that is designed to facilitate the delivery of Optical Fibre-based "*SENsing as a Service- SENaaS*". Within this infrastructure, novel optical sensing platforms, deployed within different environments, are interfaced with a Cloud-based backbone infrastructure which facilitates the secure collection, storage and analysis of real-time data. Feedback systems, which harness this data to affect a change within the monitored location/environment/condition, are also discussed. The cloud based system presented here can also be used with chemical and physical sensors that require real-time data analysis, processing and feedback.

Cloud Computing, Virtualisation, VMware, Optical Fibre Sensing, Sensing-as-a-Service.

1. INTRODUCTION

Cloud-computing, as defined by [1] is having a greater impact on sensory device service delivery.

> *"Cloud computing is a specialized form of distributed computing that introduces utilization models for remotely provisioning scalable and measured resources."*

Optical sensing technologies are becoming an increasingly pervasive presence in a wide variety of applications, being deployed in a multitude of environments. The capture, collection, storage and processing of real time data streams presents a number of technological challenges. Essentially at its foundation, Cloud-computing revolves around the effective sharing of resources, where these resources are dynamically reallocated based on demand and requirements. Resources such as processing power, storage, virtual machines, development tools etc. can be allocated based on the needs of the application. Traditionally, business applications, data processing and data analysis have very often proven to be quite complicated and expensive to effectively implement, particularly given the amount and variety of hardware and software components required to support such applications. However, with the evolution of "The Cloud" and "Cloud-Computing" technologies businesses of all shapes and sizes as well as research groups and individuals can now avail of the hardware and software environments their applications require without the need to invest heavily in new computing infrastructure. Instead, with cloud-computing capacity can be increased or capabilities can be added on the fly, without the need for investment in additional infrastructure, train new personnel, or licence new software.

Optical sensing technologies are becoming an ever more pervasive presence throughout the world in various different forms and applications and are being deployed within a multitude of environments. The capture, collection, storage and analysis of real time data streams present a number of challenges, particularly relating to the deployment of requisite resources to support the sensing applications. The utilisation of cloud-computing technologies to support the collection, storage and analysis of real time data streams generated from optical fibre sensing platforms can provide a number of benefits to researchers wishing to process and examine the data, such as: always on-line availability of data and data security management. The nature of cloud infrastructures means that the data can be made available from any geographical location and this in itself could serve to facilitate increased collaboration between geographically dispersed research groups. This is further facilitated by a wide variety of access mechanisms for accessing cloud storage spaces.

Within this paper, a layered infrastructure which aims at facilitating "Sensing as a Service" (SENaaS), within a cloud infrastructure is presented and the optical sensing technologies utilised to harness the data streams are outlined, highlighting in particular the benefits of incorporating these technologies into the cloud-based infrastructure. Finally,

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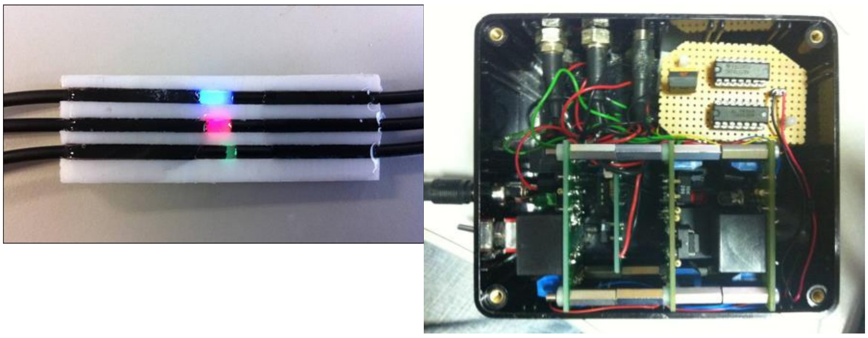
conclusions are given which show the importance of the cloud and data security to future sensing applications.

2. OPTICAL FIBRE SENSING

The use of optical fibres as a sensing media is an area of considerable growth. Among the reasons why optical fibres are so attractive are their low loss, immunity to electromagnetic interference (EMI), small size, light weight, safety due to no electrical activity and relatively low cost and maintenance. The application areas that these sensors are attracted to generally offer design difficulties for traditional sensors, such as: medical, structural, radiation/EMI and areas where sensor weight is an issue. This section includes a synopsis of two recently developed optical fibre sensor systems in which wireless, cloud storage and security technology have been designed into the detection system. These are systems for measurement of (i) water quality [2] and (ii) photoplethysmograhic (PPG) [3] including real time Haemoglobin concentration. The sensor and associated signal detection hardware for (i) are shown in Fig 1 (a) and (b) respectively. Fig 2 shows the system architecture for the PPG sensor of (ii).



(a) (b)

Fig 1. An Optical Fibre Sensor System for Water Quality Monitoring

The complexity of the signals is illustrated in Fig 3. This represents the optical (PPG) signal combined with a number of electrical signals derived from three axis accelerometers in real time.

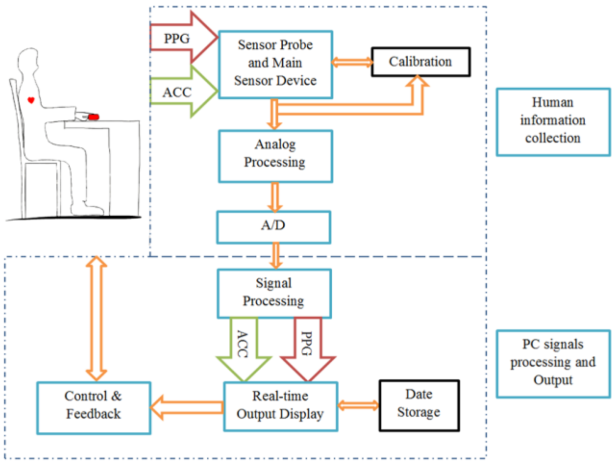


Fig 2. System Layout for Cloud Based Optical Sensor for PPG Signal Monitoring

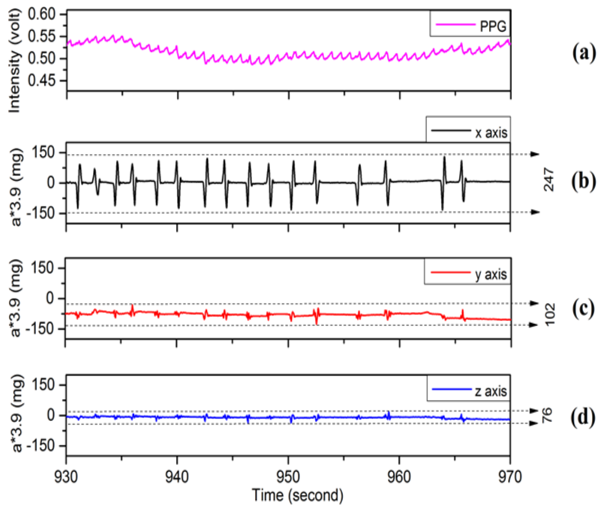


Fig 3. Real Time Data from Optical (PPG) sensor and co-located three axis accelerometer

3. LAYERED CLOUD INFRASTRUCTURAL APPROACH

Given the disparate nature of applications and technologies required to facilitate a "Sensing as a Service" (SENaaS) within a cloud-based infrastructure, the architecture presented in this paper has been broken up into a tiered infrastructure, as depicted in Figure 4. At the point of sensing, an optical fibre based sensing apparatus is applied in order to sense the chosen parameters within a particular application domain. Depending on the application, this can involve harnessing a constant data stream of real-time data, or merely act as trigger should a particular condition be met. In order to harness the data and pass it to entities which can operate on and analyse the information, the sensing component is linked to a communications platform. Based on the existing infrastructure within the application environment, these platforms can employ communications technologies such as Bluetooth, WiFi and 3G/4G in order to convey the data to the infrastructure's data-processing components. The data-processing components which have been mentioned previously exist within the Cloud-based core of this infrastructure. This is where we would discover the 'Big Data' element of the infrastructure. This element of the system will be discussed further later in the paper.

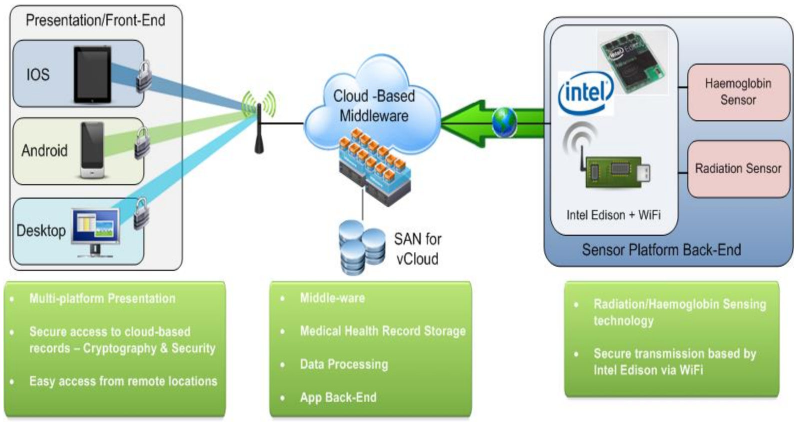


Figure 4: Tiered Infrastructure

Finally, sitting at the top of this tiered infrastructure are the systems which will benefit from the effective analysis of the incoming sensing data. This can be as simple as systems presenting extrapolated useful information though a Front-End presentation system to interested parties, or indeed, this tier can represent systems which can affect a change in the environment/condition being monitored. Essentially, this tiered infrastructure seeks to enhance and evolve the application of optical fibre based sensing to facilitate more access and utilisation of the data harnessed from these sensing platforms.

The existing cloud infrastructure within the ECE Department of the University of Limerick (Figure 5), which provides the foundation for this cloud-based sensing infrastructure, comprises two Dell PowerEdge R720 servers (with capacity for more). Each of these devices is capable of supporting up to 768Gb RAM, as well as up to sixteen 2.5" drives, or eight 2.5" drive and four PCI SSD drives. The allowance for so much storage negated the need for establishment of a Storage Array Network (SAN) in the initial phase of the project. The ability to implement the project without a SAN freed up approximately €20,000 of the budget. which in turn was invested in the servers by increasing the amount of RAM, and upgrading some of the hard disk drives from SATA to solid state.

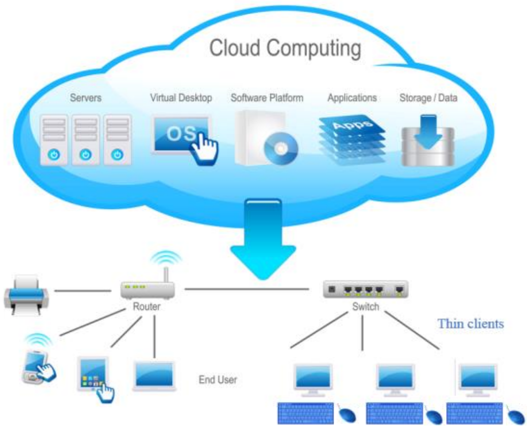


Figure 5: Representation of ECE Cloud

This extensive hardware infrastructure is managed through a VMware-based software implementation, employing VMware's ESXi and vCentre packages in particular, to manage the hardware. Finally a thin client (system with a monitor, keyboard, mouse and limited RAM) offers the user access to vast computing resources and storage but at far reduced costs when compared to traditional PC's. In addition thin clients offer low risk of theft in general and are easy to replace if stolen or broke, as such they are very suitable for access points at remote monitoring sensing stations.

Cloud Security

When considering the Cloud, two topics appear at the fore: Data Security and Big Data. The aforementioned topic, security, must also address the issues involved with data transfer to and from the cloud when dealing with (often remote) wireless sensors. According to the *CLOUD SECURITY ALLIANCE* Top Threats Working Group, the following nine critical threats exist to cloud security (ranked in order of severity):

1. Data Breaches	2. Data Loss	3. Account Hijacking
4. Insecure APIs	5. Denial of Service	6. Malicious Insiders
7. Abuse of Cloud Services	8. Insufficient Due Diligence	9. Shared Technology Issues

These threats are fully discussed in the "The Notorious Nine: Cloud Computing Top Threats in 2013" [4]. The top three threats to data security in the cloud, listed above, can generally be addressed using the services described by the CIA triad [5]. The services; confidentiality, availability, authentication, integrity of data and non-repudiation can be facilitated using conventional encryption and hashing algorithms in an organised fashion.

i. Confidentiality: Encrypting of data on the sensor node itself, during transfer and storage in the cloud will help preserve data confidentiality.

ii. Availability: Service availability can be provided and guaranteed (as much as is possible) by the provision of suitable firewall technology.

iii. Authentication: Data transmission between nodes and cloud storage must be verified. These services can be provided using a combination of encryption and hashing algorithms to provide MACs – Message Authentication Codes.

iv. Integrity: The same hashing algorithms that can be used to provide source and data authentication are used to provide data integrity services.

v. Non-Repudiation: of origin and/or destination are necessary services to ensure the legal source and destination of data when dealing with cloud based services. They can be readily provided by the use of encryption and hashing algorithms.

Suitable high speed hardware implementations of encryption and hashing algorithms can maximise the usefulness of such services and limit their effect on sensor node resources such as power and memory. In addition the algorithms can be organised in such a manner that any high computing requirements can be placed on the cloud storage providers where computing power can be virtually unlimited.

Data Analytics (Big Data)

Cloud computing has become a viable, mainstream solution for data processing, storage and distribution, but moving large amounts of data in and out of the cloud presents a seemingly insurmountable challenge for organizations with terabytes of digital content. Cloud computing promises on-demand, scalable, pay-as-you-go computing and storage capacity. Compared to an in-house datacentre, the cloud eliminates the need for large upfront IT investments, letting businesses easily scale out infrastructure, while paying only for the capacity they use. Big Data is an all-encompassing term for a collection of data sets so large and complex that it becomes difficult to process using traditional data processing applications to extrapolate useful information from a continuous stream of incoming data. This is a facility that the Cloud can readily provide with its access to potentially unlimited computing storage, processing and power.

The sensing as a service infrastructure proposed in this paper will operate in a similar fashion to the business model for Software as a Service (SaaS) where users are provided access to application software and databases. SaaS is sometimes referred to as "*on-demand software*" and is usually priced on a pay-per-use basis or using a subscription fee. Using this model the users of the SENaaS infrastructure simply have to position the sensors required and the cloud will provide and operate all application software, additionally all data is stored and processed securely in the cloud. The benefits associated with this are that users of the various sensing systems do not need to understand or manage the cloud infrastructure and platform where the applications run. This greatly simplifies maintenance, support and service growth issues associated with specialist software that clients would be unfamiliar with.

4. CONCLUSION

The "SENsing as a Service SENaaS" system described has many benefits. Future sensor applications and the environments/conditions that they are monitoring may vary widely in scale, accessibility and connectivity. To date there is no one solution fits all for monitoring, data storage and analysis. Therefore a likely 'best approach' is to utilise a multi-faceted approach in which many different types of sensing techniques can be utilised but connected to a common storage and analysis platform. We argue that the most suitable platform for this will be cloud based such as the system presented here. Not only should there be a multi-faceted approach to sensing but there also needs to be a multi-faceted approach to the relaying of the information back to the end user. This will place added requirements on middleware platforms to aggregate data from multiple sensors that can interface with multiple sensor types and support the analysis of growing volumes of diverse data. The cloud based layered infrastructural approach outline in this paper is ideal for this requirement.

5. ACKNOWLEDGMENT

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