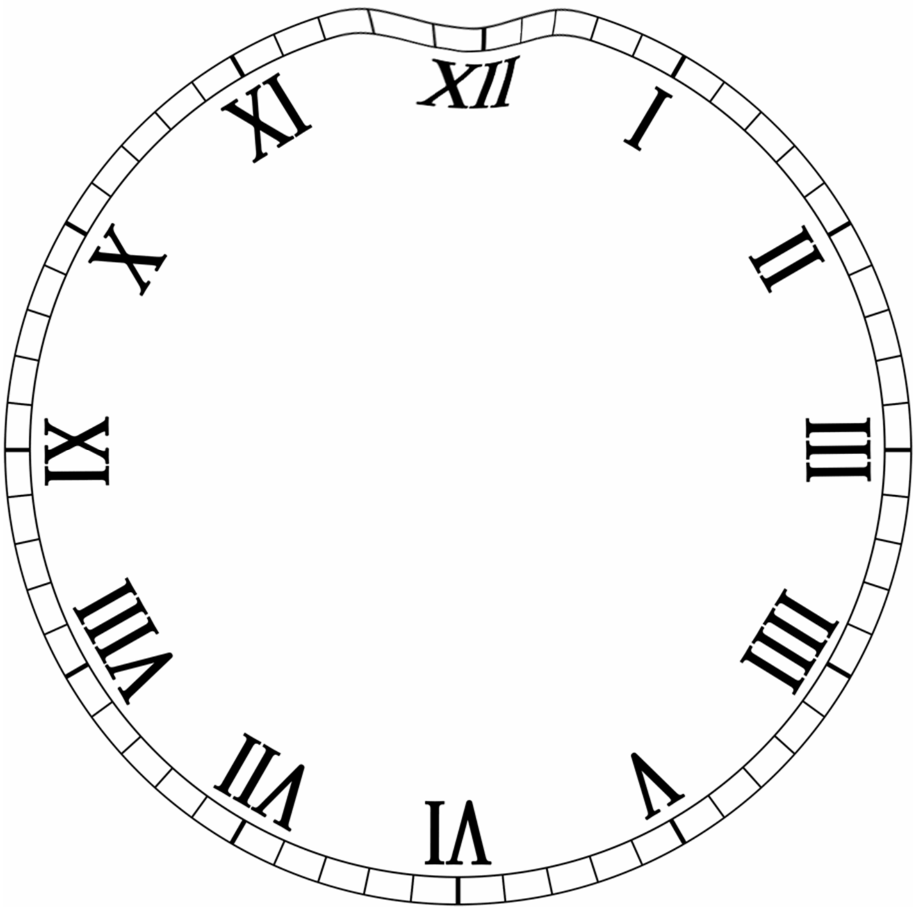

A WRINKLE IN TIME

CHALLENGES in TIME AWARE COMPUTATION - SYNCHRONIZATION

The Time Lab

Abstract

Time influences every action and must be guaranteed for a subset of actions to prevent loss of life or trigger a cascade of potentially cataclysmic events. Precision timing in computational instruction sets and transmission of such instruction to actuate or execute is increasing in importance with the growth of the medium of the internet as a vehicle for real time communication. It appears that integration of real world physical objects with hardware and software is lacking the rigor expected from cyberphysical systems if the semantics of time were an integral part of the architecture. Hence, the marriage of data and time is a challenge for true time aware computation.

Background

I have prepared a simple tutorial (http://tinyurl.com/SD-86935 work in progress) to illustrate the imminent tsunami of connectivity. We are on the cusp of an internet mediated revolution which is entering its fourth phase and embracing interactions with mechanical objects (for example, spinning parts on drills in oil exploration or mining industry) in addition to the internet of things (IoT). The latter is a human-centric approach catalytic for lifestyle changes by weaving into our daily lives objects and processes with which we interact (cars, healthcare). An equally powerful and parallel segment of this evolution is the emergence of cyberphysical systems (CPS).

The Core Problem Space - Time

Common talk about timing as data is a misrepresentation and lacks differentiation. Timing in its various forms is incompatible with data systems (computers, applications, communications systems). These systems divorce themselves from the physical layer by design, yet timing, as a signal, is fundamentally physical. Data systems (computers, communications systems) have made progress by encapsulating function. This isolates each function and allows for independent development (programming uses modules and communications has layers). Timing is a signal, it is not data. We need to differentiate signal from data. Timing (signal) cannot be removed from the physical layer without distorting it. The lack of convergence of data systems and timing (encapsulated functions and the physical layer) is the fundamental reason behind uncalibrated delays, jitter and wander in time transfer (synchronization). Currently, timing is injected into data systems as an outside system. This method of adding timing outside the core design will not scale adequately with billions of devices and trillions of end points anticipated in the context of CPS, IoT and the future of the industrial internet. Since timing and data is inextricably linked to geo-location, privacy and security issues, timing needs must be considered in the broader context of cybersecurity and integrated in the design of reference architectures with a focus on public key infrastructures, digital certificates, authentication protocols and network intrusion detection systems. The marriage of data and time is a frontier area for research and may segue to the development of new products, new services and new lines of business.

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Introduction to Time – Made Simple

The simplest way to understand the importance of time is to differentiate between the industrial internet, the internet of things (IoT) and cyberphysical systems (CPS) with respect to the notion of time. It may sound obtuse, amorphous and obfuscating but it is as simple as time. The profound implications of time awareness may be one reason why serious exploration of CPS is exploding in the US, EU, India, China and Japan, to name a few countries with dedicated CPS programs. The dependencies and interrelationships between CPS, industrial internet and IoT may be blurred by the need for time centricity, correctness of time and time guarantees.

If you want to send a text message, you send it and the SMS arrives at its destination after a few minutes. Does it really matter if it is 1 minute or 2 minute or 10 minutes? If it matters, then you would rather call for an instant (almost instant) response. Wouldn't you? Therefore, the time centricity of a text message (1-10 minutes) vs the time centricity of a phone call (1-2 minutes) are distinctly different. What about the time centricity of hitting the brakes while driving your car when you see a child running after a soccer ball in the middle of the road? In an "instant" but that "instant" in time centric terms may be in seconds or less depending upon the state of your neurological response system.

Fast forward to 2062 and imagine that you are a back seat passenger lounging in an autonomous (self-driving) automobile. Repeat the scenario in your mind – a child runs out in front of your autonomous automobile. It is obvious that the response of the vehicle is time critical. The NHTSA will demand time guarantees (that match or closely mimic the threshold of human operators) from the manufacturer of the autonomous automobile with respect to its ability to respond to such uncertainties. The autonomous automobile manufacturer will have sensors to detect activity within the range of the vehicle. This detection system will detect the child in harm's way. What will the sensor-detector do with that data? Send the sensor data to the fog or the cloud for analysis may be one answer (http://bit.ly/mCLOUD). The fuzzy analytics from the foggy cloud will send a message to the actuator – in this case – brakes – to initiate the process – which will result in the application of the brakes by the autonomous vehicle. How much time has elapsed (in this cloud of things approach) before the actual application of the brakes? Is this time delay in the cloud or the fog (of things) acceptable and capable of preventing a mishap?

What if the sensor detector could directly communicate the output (child in harm's way) to the brake system and initiate the application of brakes? Will the direct approach save a few milliseconds and avert the accident? What if the sensor detector is sending the information to a software control system (proportional-integral-derivative controller or PID controller) which in turn performs its analysis of the data (proportional-integral-derivative) and then instructs the "brain" of the braking system, which sends a command to initiate the application of brakes? How much time has elapsed in communication between the various embedded systems? What is the time necessary for the software (a separate entity) to talk to the system and the system to interact with the brakes (a physical system, that is, objects obeying the laws of physics)? Is this happening in time for the autonomous automobile to avoid hitting the child?

What if we could combine (integrate) the computation, networking and physical processes? In other words, can we combine in one end-to-end system the physical component (brakes) and the necessary chip (silicon) which will perform the computation (hardware) and the instruction set required for data and analytics (software)?

Yes, we can. We can, in the future, develop a time guaranteed cyberphysical system which can be certified to reliably perform and execute under a set of time critical constraints.

In relative terms, time and the concept of time criticality, is bounded in different domains, depending on the activity (for example, consider the photo sharing site Instagram vs vehicle brakes). The not-so-instant Instagram is in the IoT dimension whereas the braking system of an autonomous automobile is in the CPS dimension of time.

Achieving the CPS dimension of time and reducing the time lag between the sensor and the actuator is an area (system latency) of intense research and fundamental to advancing time criticality in cyberphysical systems. The intense coupling of the physical object with the hardware and the software is key to the future of CPS.

The dependency on this extreme coupling necessary to guarantee and certify CPS systems is responsible, in part, for the cost structure and operations of such systems. For example, what if the software in the autonomous automobile was subjected to an "update" which we frequently encounter with operating systems running on our personal devices (smartphones, laptops)? A software update downloaded automatically to the systems operating in an autonomous automobile should immediately rescind the time guarantee related performance specifications and certification from NHTSA. The acceptable latency threshold may change with the updated software. The entire system must be re-certified with the new parameters.

Therefore, five years after you have purchased the autonomous automobile, the software in your vehicle's system has advanced but you cannot risk the newer, better, faster version of the software unless you subject your car to re-certification by the NHTSA. If you update the software in your vehicle and do not re-certify (at a considerable expense) then the NHTSA and your insurance company can legally instruct your manufacturer to disable your car from operating and your manufacturer will comply. Your autonomous automobile with improved software is stationary because of time!

You decide to bypass the software because of the need for re-certification and you choose to focus on improving your hardware. You purchase Intel Xeon multicore chip and hire the Geek Squad to perform the upgrade. Moments later NHTSA shuts down your vehicle. Why?

This time it is jitter. No, it is neither the jitter bug nor the jitterbug!

Jitter is the undesired deviation from true periodicity of an assumed periodic signal. Jitter is ubiquitous in electronics and telecommunications, often in relation to a reference clock source. Time - time and time again! This time the ill effects of potential jitter manifests itself as a property or characteristic of clock time. The clock speed (clock time) is likely to be different between your old chip (hardware) and the new chip (new hardware). Therefore, jitter can change the time functions of your highly integrated CPS system (brakes in autonomous automobile) and require NHTSA re-certification for the vehicle performance with time guarantee specific to the new chip (hardware) you just installed.

It might be a minuscule amount of comfort to know that you are not alone in this CPS driven predicament in time. You are in good company and you have friends who are this pickle, too. Your friends are Boeing and Airbus and Embraer.

In fact, all manufacturers that make cycle systems have this problem. CPS research needs to address this problem. Today, if a manufacturer plans a production run then they must stockpile ***all*** the electronics necessary for this production, for the ***entire lifecycle*** of the product. For example, if Boeing introduces a new aircraft then they expect to manufacture it for about 50 years. Boeing may be manufacturing Boeing 777 in 2030 and they will be using hardware (microprocessors, chips) that were made in 1990. Boeing bought all the hardware necessary for a 50 year production run and they store these chips in liquid nitrogen because the natural diffusion processes in the silicon may render these chips non-functional, if stored otherwise.

What? In 2030, Boeing is still going to use microprocessor technology from 1990 to produce 777's? Yes.

This is the magnitude and scope of the CPS problem space in time and the enormous value of solutions that may emerge from CPS research. A solution for time in a framework where time is absolute, not relative.

But what does a microprocessor execute? Synchronous digital logic running single-threaded imperative programs. Any chip will correctly execute that program. Correct? Yes. Then, what is the problem? The problem is with the model. Unfortunately, the deterministic model does not say what needs to be done. It is not a part of the model. It does not say how this program should interact with the physical world. The model is useful for describing algorithms but it is not useful for describing cyberphysical dynamics. The coupling and the integration with the physical world is simply not in the model. Therefore, Boeing and others are stuck with the physical implementation of this chip in the context of the physical world of the Boeing 777 designed with the performance criteria germane to this chip (this specific microprocessor) based on the silicon on which this chip was etched. This why Boeing must stockpile the components for the entire production life cycle of the 777 to prevent the costly re-certification (if necessary).

Hence, major inefficiencies creep in the system and inflate cost of operation because in this 50 year span you are barred from the benefits or advantages that improvements in the hardware could offer. If you want to reduce cost of power by using improved chips then you must re-test the complete system. Re-certification is critical because the correct execution of a program in any widely used programming language has nothing to do with how long it ***takes*** to do anything. It has no bearing on correctness or time guarantee for time criticality.

If time criticality is non-negotiable in your business (autonomous automobile, pacemaker, in-flight dynamics of jet engine efficiency) then, one solution calls for re-visiting the semantics of time in the instruction set architecture (ISA). Today, programmers must step outside the programming abstractions in order to specify timing behavior but the programmers have no map of the physical systems. However, timing has not been ignored by computer science but its application is in a different context. Timing for computers (today) acts as a performance metric not a correctness criteria. Correctness is about the relationship between the physical system in the CPS model.

According to Edward Lee (UC Berkeley), therefore, the first challenge in CPS is to change the programming model so that a correct execution of the program always delivers the same temporal behavior up to some degree of precision. CPS research and solutions are vital to our global economy in the era of the industrial internet because correctness of time can make a difference between life and death (jet engines in flight, remote surgery, traffic uncertainty). The industry can expect a plethora of products and services to emerge from CPS research in time.

Time is Money – Who is spending the money for time?

FY2014 funding (US$ millions) ● http://bit.ly/iic-funding

NSF	1,227.4
DOD	881.5
DOE	541.2
NIH	526.7
DARPA	418.6
NIST	143.7
DHS	76.5
NASA	76.4
NOAA	26.1
AHRQ	25.6
NNSA	17.0
EPA	6.0
DOT	1.5

The EU is active in R&D (http://ec.europa.eu/research/index.cfm) and in addition to pre-existing programs (http://bit.ly/EU-OTHER), the new ICT funds are from FP7 Horizon 2020 (http://bit.ly/H2020-LIST) which was approved for €80 billion through 2020. Research areas are listed here http://bit.ly/H2020-CALLS and selected H2020 funding availability related to the industrial internet, IoT, M2M and CPS are provided in the table below:

DEADLINE	TOTAL FUNDING (€)	Broad Area ● R&D Topic	URL
05/07/2014	92,320,000	Smart Cities	http://bit.ly/H2020-Lighthouse
08/28/2014	47,000,000	Privacy	http://bit.ly/H2020-PRIVACY
08/28/2014	10,000,000	Smart Transportation	http://bit.ly/H2020-ngTrans
11/25/2014	125,000,000	5G Network Infrastructure	http://bit.ly/H2020-5G
12/09/2014	145,000,000	Manufacturing	http://bit.ly/H2020-Manufacturing
03/03/2015	108,180,000	Smart Cities	http://bit.ly/H2020-SmartCity
03/31/2015	144,500,000	Autonomous Automobiles	http://bit.ly/H2020-UAV
03/31/2015	21,000,000	Aviation and Aeronautics	http://bit.ly/H2020-Aviation
04/21/2015	9,200,000	eGovernment	http://bit.ly/H2020-eGOV
04/21/2015	162,000,000	eHealthcare	http://bit.ly/H2020-Healthcare
04/21/2015	49,600,000	Cybersecurity	http://bit.ly/H2020-Security
08/27/2015	144,500,000	Autonomous Automobiles	http://bit.ly/H2020-UAV
08/27/2015	30,000,000	Electric Vehicle Integration	http://bit.ly/H2020-EV-grid
08/27/2015	18,500,000	Innovation in Transport	http://bit.ly/H2020-iTrans

What money can buy? *Spending the money for time research may buy us more time to live even longer lives*

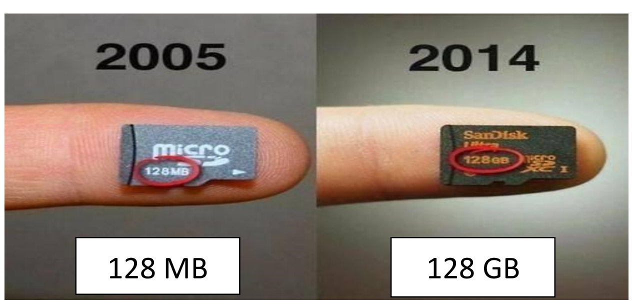
About 10 million people may be using pacemakers (http://circ.ahajournals.org/content/105/18/2136.full) by 2020. Let us assume that 10% of the users (1 million) may use a system where the manufacturer of the pacemaker may upgrade the system by downloading firmware to the devices using software defined networking. Under our present system, it adds timing as an external element in the design of the device. It may be harmless for 90% of the users who receive firmware updates. But, for 10% of the 1 million users (100,000 patients), the wrinkle in time may be fatal, for example, in an arrhythmia (supraventricular arrhythmia, atrial fibrillation or atrial flutter) where time criticality is paramount in controlling the time and frequency of the signal from the rate-responsive pacemaker to stabilize the heart. Lack of time guarantee following the firmware update may cause 10% of these patients (10,000) to suffer (morbidity) and 10% of those who are suffering may eventually succumb. *The cause of death of these 1,000 patients can be traced to time*. Hence, the need for marriage of data and time.

Standardization of Time - Interoperability is Essential to Reduce Global Socio-Economic Friction

The future of business is not as usual and the socio-economic changes ushered in by connectivity will morph the tapestry of civilization. To be the purveyor of economic growth it is necessary to act collectively, sponsor innovation and break down silos. Progress may be measured by our ability to interoperate between systems, objects and devices in different environments supporting different standards of operations, protocols and applications. It is impossible to expect that the world will strive to support one common standard, even for time.

Hence, not standardization *per se* but the *interoperability* between major standards will be the key to diffusion of the products and services which may reach into the domain of all things mechanical. Industry leaders must enable open standards for interfaces (APIs) where products from SMEs can plug into a common global bus to access the connectivity and add their value added services, analytical engines or enhance niche applications. The *systemic* deployment of open connectivity backbone is central to data acquisition, time synchronization and the spread of the industrial internet of smart things through collective efforts, standardization and complementarity.

According to Jeff Immelt of GE, "in the future one expects an open, global fabric of highly intelligent machines that connect, communicate and cooperate with us. The Industrial Internet is not about a world run by robots, it is about combining the world's best technologies to solve our biggest challenges. It is about economically and environmentally sustainable, energy, it is about curing the incurable diseases, and preparing our infrastructure and cities for the next 100 years."



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THE TIME LAB

Time is a super set of fundamental principles of research which will influence the future of networked society and human interactions. To advance the field of research in time, one may start with a focused research lablet dedicated to time and supported by academic-industry-government partnerships similar to Project Oxygen.

This lablet may evolve in future to morph as THE TIME LAB in the image of The Media Lab. For an even grand and inclusive vision, it may be housed in the Center for Networked Society or Center for Networked Systems, which, when abbreviated (CNS) triggers an imagery of convergence, connectivity and spatio-temporal centricity.

THE CAMPAIGN for THE TIME LAB

Communicating to the industry the fundamental principles of time research and its imminent marriage with data is expected to trigger multiple verticals to grasp time criticality as an essential element in its QoS metric for future products and services. In time, The Time Lab, will embrace, seek and support new lines of research and industrial or commercial applications of the research outcomes which may lead to new products and services which industry may adopt (license). The outcomes may spawn a plethora of start-ups to create new products and services. New dimensions are likely to erupt from time research. The ecosystem will move far beyond the conventional industries (telecommunications) and spill over on to the unchartered path within a decade.

The hockey stick profile will gather critical mass and enter a new phase when The Time Lab celebrates its 10^{th} anniversary with the emergence of a network of similar centers or labs in various universities around the world (MIT Media Lab in Ireland, India and MIT Auto ID Labs in various countries). The Time Lab in various parts of the world will source the brightest scientists and fuel even more innovation at MIT and catalyze global job creation.

The Director of The Time Lab or CNS will be someone fiercely eminent with global name recognition, radiant personality and unparalled brilliance (eg Dina Katabi or Claire Tomlin) who may act as a purveyor of civilization.

Acknowledgement – Ideas have origins. I wish to thank individuals who inspired me to think. They include Glenn Seaborg, Clive Granger, Charles Townes, Robert Curl, Harry Kroto, Larry Jameson, Sanjay Sarma, Paul Kern, Joseph Salvo, Jean Walrand, Edward Lee, Kris Pister, John Eidson, Marc Weiss, Julian Goldman, JrJung Lyu, Daniel Kahneman and colleagues in various institutions. Thank you - *Shoumen Datta*

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Is Timing Sacred in Healthcare?

An eight-minute difference [was noted] between the Epic [sic] computer and the cardiac monitor. This shows a delay in care where there is a patient issue (i.e., pain medications, blood pressure medications). (Accurate blood pressure does not correlate with time issue occurred.)

www.patientsafetyauthority.org/ADVISORIES/AdvisoryLibrary/2012/Dec%3B9(4)/Pages/143.aspx

Introduction

It requires no stretch of imagination to understand that sampling frequency programmed in a medical device must be adaptable to the context of the patient. At the least, the time stamps must be accurate using a bonafide reference (eg NTP). Synchronization and interoperability of medical devices with platforms are quintessential to the future of healthcare if secure remote monitoring and cyber-surgery are expected to be adopted. Timing in healthcare could spell the difference between life and death.

The Inextricable Trinity – Platforms, Interoperability and Timing

At the heart of this arena is the time synchronized development of verified and secured medical device software and systems from verified closed-loop models of organs and devices (for example, cardiac pacemakers and physiological control systems, such as drug infusion pumps).

In the current context, the view of platforms and interoperability excludes time, which is a physical entity in the form of a signal). The discussion and development of platforms and interoperability is almost exclusively focused on data as a function in the software domain. Hence, the notion of platform is essentially data centric with data distribution and data interoperability between various software packages occupying the bulk of the healthcare "interoperability" debate. The notion of time does not appear to surface as frequently as it should and almost absent from the domain of big consulting firms.

The political spectrum of platform and interoperability issues are related to book-keeping practices commonly referred to as electronic health or medical records (EHR, EMR). Spurred by the growth of telemedicine efforts to reach rural segments of the US population, it appears that the telemed "format" and EHR formats are not interoperable. Agencies in this debate (FHA, OSEHRA, FDA) are keen to standardize platforms but their definition of the salient features of a "platform" is long on function (software related to data acquisition and distribution) and short on time (signal). Current bills in the US Congress which addresses the conventional wisdom about platform and interoperability is as follows:

1. Devin Nunes (R-CA) and Frank Pallone (D-NJ) Tele-Med Act - http://bit.ly/Tele-Med-Act
2. Matsui (D-CA) & Johnson (R-OH) Telehealth Modernization Act - http://bit.ly/TeleHealth-Matsui
3. Gregg Harper (R-MS) *et al* - Telehealth Enhancement Act - http://bit.ly/HR3306-TELEHEALTH

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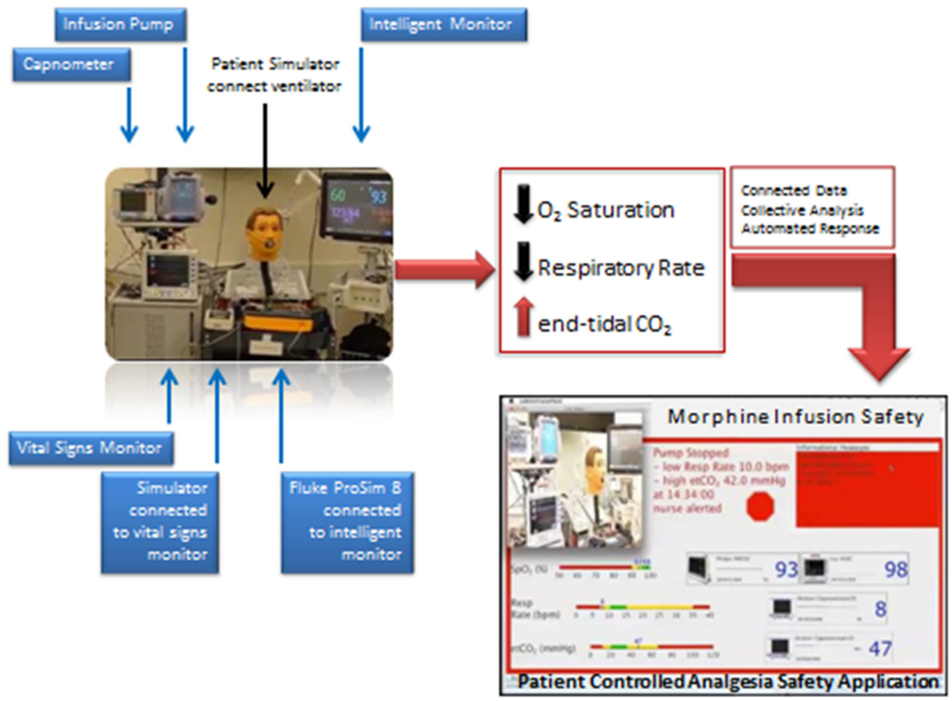
Medical Device Integration – Prerequisite for time synchronization ?



www.mdpnp.org/devicesynchronization.html

The vital importance of systems and device integration for healthcare solutions cannot be over emphasized. Application-specific sensors for individual functions are essential components but evaluation of the patient's condition, rarely, if at all, depends on any one physiological criteria. Therefore, connectivity of relevant sensor data fabric, followed by data-dependent analysis and consequent autonomous response, in real-time, in the context of the appropriate process, is at the heart of the advances necessary for healthcare. The need for real-time responses makes healthcare a challenging time-critical topic in the cyberphysical systems (CPS) research. Application aware networking must trigger time guaranteed interaction at the point of contact (PoC) based on healthcare data on the platform. Time dependencies integrated with secure EHR/EMR and HIT (healthcare information technology) are central to the quality of service (QoS) at the PoC, if we claim to improve the delivery of healthcare on-site or off-site (remote monitoring, telemedicine, cybersurgery, online consultation). It is necessary to address the role of *ad hoc* authorized users vs security and privacy of the patient and the context of the patient. It is likely that the data will exponentially decrease in value, unless accessed and analyzed in real-time in order to execute automated response or provide feedback or alerts, to the nurse or physician, at the point of contact (hospital, home, primary care, nursing home, assisted living).

In post-surgical patients or post-anesthesia settings the first sign of an abnormal or compromised breathing pattern may be indicative of airway obstruction or respiratory distress. The latter may be compounded and may be fatal in patients with (prior history of) chronic obstructive pulmonary disease (COPD may include chronic bronchitis and/or emphysema). Respiratory rate sensors using acoustic monitoring can noninvasively and continuously measure respiration rate using a sensor with an integrated acoustic transducer that is attached (in an adhesive band) to the patient's neck.

Using acoustic signal processing, the respiratory signal is separated and processed to display continuous respiration rate. Continuous monitoring of respiration rate is especially important for post-surgical patients receiving patient-controlled analgesia (PCA) for example, morphine, for pain management. Analgesia induced sedation can induce respiratory depression and place patients at considerable risk of serious injury or death.

Generic respiratory rate sensors are often stand-alone sensors specific for respiration and with a basic visualization or alarm system connected to the nurses's station.

The other commonly used sensor is the pulse oximeter. It is a non-invasive device to measure blood-oxygen saturation level (SpO_2) and pulse rate. It is essential to monitor blood oxygen saturation for a chronic disease, such as, COPD. Wireless data transmission using Bluetooth is common and device bundled data software management provides viewing, analysis, reporting and data storage for basic oximetry screening applications.

Generally, pulse oximeters are also stand-alone SpO_2 sensors with a basic visualization or alarm system connected to the nurses's station.

Due to excessive case load as well as an abundance of diverse, uncoordinated and widely distributed monitoring equipment, it is not uncommon for attendants to ignore the first few alerts originating from either sensor(s) from patients. Action may be initiated only when attendants may notice that the respiration rate and blood-oxygen saturation level are both decreasing, simultaneously, in a patient. For patients receiving patient-controlled analgesia (PCA) for example, morphine, for post-surgical pain management, the analgesic-induced sedation can induce respiratory depression and patients may die due to delayed sense and response or simply due to human error caused by unintegrated sensor systems.

Connected data, collective analytics and real-time coordination of autonomous response may prevent the mortality and potential morbidity (if distress is not fatal but causes paralysis).

The Internet of Healthcare (?) in the future Networked Society may enable integration of various sensors and monitors which will feed an autonomous execution application designed to focus on the patient receiving patient controlled analgesia (morphine). The application will monitor the data fabric for data that has been configured as relevant to this monitoring and specifically address the process of administration of the analgesic as long as the analgesia is improving the patient's quality of life.

In this illustration the monitoring integrates sources of relevant data, that is, oxygen saturation, respiratory rate and $etCO_2$ (end-tidal carbon dioxide).

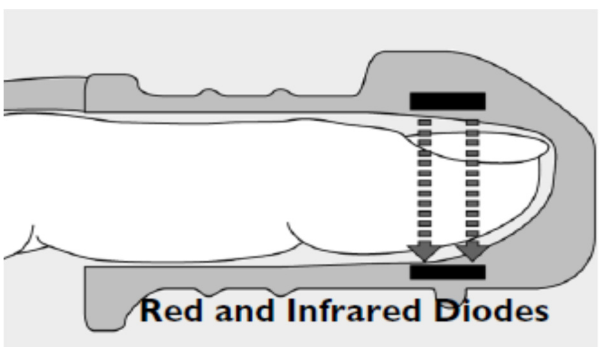
In a simulated case, if the sensors are not integrated on the same platform, a warning message may flash on the screen to indicate that all of the sensing devices are not connected to the system, for example, respiratory rate sensor. It is required for this application. The illustration (above) shows a CAPNOMETRY device which can be connected to supply respiratory rate data.

The adapter, when connected to the capnometer (measures respiration rate) triggers a discovery process within DDS [Data Distribution Service] and advertises to the rest of the participants on the system that data is available for respiratory rate and $etCO_2$. An open source Linux arm-based computer is used as a device connectivity adapter running software available on Sourceforge (open source). On the serial port side it may be using proprietary protocols for each device. On the internet side it may utilize an OS implementation of DDS to create a global system data fabric, which is then available to applications, such as the infusion safety application, required for the function and control of the infusion pump delivering the morphine. These systems may be connected to the backbone platform.

In this PCA scenario, the control of the delivery of morphine is the key point of regulation. The regulatory process must coordinate the data from the various relevant sensors and the vital signs of the patient in order to control the activity of the infusion pump (desired key outcome is the regulation and control of the pump).

The infusion pump application, therefore, must find necessary sources for the data including oxygen saturation from both the intelligent monitor as well as the IV monitor. It draws respiratory rate and $etCO_2$ values from the capnometer. By virtue of the DDS this data could originate from any device configured with the same data schema and made available as an open source code (Sourceforge, Github) to create devices which are interoperable (in this case) with the infusion pump, running this application, connected to the "platform" which, in the future internet architecture model, may include the semantics of time as a systems abstraction, which is not the case at present (http://bit.ly/TIME-JG).

CASE 1: To test this application, the simulation induces a transient desaturation event using the Fluke ProSim 8 vital signs electronic stimulator that is feeding optical signals into the finger clip (pulse oximeter measuring SpO_2 oxygen saturation).



The finger clip houses the sensor. Within the SpO_2 sensor, light emitting diodes shine red and infrared light through the tissue. Most sensors work on extremities such as a finger, toe or ear. Blood, tissue and bone at the application site absorbs much of the light. However, some light passes through the extremity. A light-sensitive detector opposite the light source receives it. The sensor measures the amount of red and infrared light received by the detector and calculates the amount absorbed. Much of it is absorbed by tissue, bone, venous blood, but these amounts do not change too much over short periods of time. The amount of arterial blood does change over short periods of time due to pulsation (although there is some constant level of arterial blood). Because the arterial blood is usually the light absorbing component which is changing over short periods of time, it can be isolated from the other components. The amount of light received by the detector indicates the amount of oxygen bound to the hemoglobin in the blood. Oxygenated hemoglobin (HbO_2 or oxyhemoglobin) absorbs more infrared light than red light. Hb or deoxygenated hemoglobin absorbs more red light than infrared light. By comparing the amounts of red and infrared light received, the instrument can calculate the SpO_2 reading.

The pulse oximeter is connected to the intelligent monitor. Based on the desaturation event simulation the monitor records a transient drop in oxygen saturation. In the real-world, this drop may be caused by

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the patient gripping a telephone handset or bed rail or pretty much any movement can induce the failure mode of the pulse oximetry finger clip. This drop in value will be displayed on the field monitor. If it drops just slightly and if it is temporary then the application generates a warning message. If the desaturation simulation does not last for long, the application does not generate an alarm and the Morphine (analgesic) infusion continues. As the desaturation ends and oxygen saturation value ($Sp0_2$ reading) increases, the message or alert will disappear from the display and an alarm is not generated in this scenario. Infusion of pain medication continues, as indicated by the green light over the model of the infusion pump on the display monitor.

CASE 2: The next simulation combines two pieces of data: $Sp0_2$ reading and respiratory rate to create a corroborating simulation to indicate that the patient's condition is deteriorating. By integrating both data for action, if they both go down simultaneously then the action follows with a very short latency. In the simulation, a nurse call will be activated and the infusion will be automatically stopped (temporarily, as an interlock) to allow for intervention. The simulator will drop the patient's respiratory rate and create another desaturation event using the Fluke simulator connected to the intelligent monitor. Data from the capnometer will show that due to the reduced respiratory rate the $etCO_2$ has increased. The application has detected this factor. As the desaturation continues in the simulation the simultaneous drop in $Sp0_2$ reading and the respiratory rate triggers a rapid increase in $etCO_2$ which executes an automated response by activating a safety interlock to stop the infusion pump from delivering morphine. The green light on the infusion pump disappears. Hence, the connected data fabric prevents the action of the infusion pump to stop the flow of analgesic and initiates a red alert for the patient's condition which is communicated to the nurse / physician. This is a time-critical event and time concurrency is important in the process of systems integration.

COMMENTS

My ramblings in the context of time are aimed to evoke discussions between scientists, engineers, practitioners, economists, operations experts and manufacturers involved with devices, management and delivery of services via the IoT. CPS research related to time, charts an unchartered path for IoT, healthcare and the future industrial internet of intelligent machines. It is expected to be a subset of a major (healthcare) initiative under an august umbrella to bring together global industry players, academia and government to create a forum which may help to usher an open and global platform to serve the dual role of operational management as well as a technology backbone, synchronized in time. The platform of the future must be capable of [1] implementing plug-n-play security, [2] adaptable privacy in distribution of data and de-identified data transmission [3] real-time analytics where data triggers embedded tools to suggest potential answers/solutions without revealing the intelligence of the engine kernel. The latter may fuel innovation and trigger out of the box granularity. It may harvest global brain-power, similar to apps for the iStore (think micro-payments, think profit) but different because the open source platform offers interfaces, connectivity and complementarity. Economic growth engines of the future may include analytical machines with unique algorithms and embedded intelligence which exemplifies interoperability of standards and remains platform agnostic. The channel masters share the financial tsunami from pay-per-use micro-revenue from users at the edge who are in quest for intelligent information based on data in context and data with real-time transactional value.