Guide to Cyber-Physical Systems Engineering

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Introduction

Right now there is considerable interest in Cyber-Physical Systems (CPSs). CPSs are being deployed in many domains to make savings in cost, quality of service or efficiency. Millions of Euros every year are being invested in research and innovation in this field.

In this brochure you can learn more about CPSs and why you should be thinking about how CPSs can benefit your business. In the next few pages you can read case studies from real-world businesses located around Europe who are employing CPS technologies to reduce costs, improve efficiency or better their products and services. You can, too.

This brochure is divided into three sections.

Part 1: What is a Cyber-Physical System? A short, simple case study explains some of the key features of a CPS.

Part 2: Common CPS opportunities and challenges. A collection of case studies from real-world businesses, explaining what businesses hope to achieve and some of the challenges they face.

Part 3: Applying CPS engineering principles. Read a case study of two SMEs in Spain, applying their expertise in an emerging new CPS domain, and see how they cope with some common challenges.

Contents

Part 1: What is a Cyber-Physical System?

Cyber-Physical Systems (CPSs) are systems that include some element that interacts with the physical world (e.g., sensors or actuators), and some element of complex computation. This makes them related to, but different from, embedded systems. Embedded systems also involve some element that interacts with the real world, but, unlike a CPS, typically have only very limited computation.

In a CPS, the separate system parts are usually distributed, and therefore communications are an important part of a CPS as well. The separate constituent parts (sensors, actuators, software, etc.) of the CPS collaborate together to create some global behaviour. CPSs are increasingly being deployed as (potentially large) collections of wirelessly-connected sensors which collect information about an environment, together with advanced software services which can analyse the large amount of diverse data produced. In many cases cloud resources are used in order to provide data processing and/or storage.

Once processed, the data can be used for several purposes. For example, a CPS can be used to collect information purely to understand how a product is being used, to gain a better understanding of customer requirements. Alternatively, data may be collected about current system or component performance, in order to make predictions about maintenance requirements, or to plan component replacement. CPSs can even be used to

> ***Cyber*** **means "software", and *physical* means "interacting with the physical world"**

identify changes in the environment, such as newly emerging requirements, or faults arising in the system, and then react to them. A typical CPS might:

- Monitor and control physical and organisational or business processes
- Be a large-scale system with goals spanning different application domains
- Require integration of different technical disciplines and different application domains
- Require a high degree of dependability
- Involve substantial user involvement/interaction
- Continuously monitor and optimize its own performance
- Adapt and evolve constantly in response to changes in the environment, through real-time (re)configuration, deployment or (de)commissioning
- Be a distributed and interconnected systems of system
- Require different engineering and software development competencies.

Cyber and Physical

Interactive media campaigns

Merlyn-Electronics, based in the UK, is an SME that provides custom electronic systems. On this page is described a system designed and built by Merlyn that has cyber-physical features (you can find other examples of CPSs throughout this brochure.)

Merlyn-Electronics has developed a system called '"Showscreen" which is used to deliver interactive advertising campaigns. The "Showscreen" devices are distributed throughout a region or city. They offer a method for members of the public to interact (e.g., a tough touchscreen). Passers-by are incentivised to interact with the device through competitions or free product samples. The device has several important elements:

- It must be capable of interacting with the physical world, through sensors and actuators
- It must be linked to many other devices in a region which co-operate to deliver a single co-ordinated campaign – it requires communications and access to software services

These are the fundamental elements of a CPS: connectivity, elements that interact with the physical world, and computational capability. Although this is a simple example, it's possible to build CPSs with large numbers of sensors that can gather large amounts of information about their environment.

The Showscreen systems face some particular challenges. Devices may need to tolerate hot, cold or wet conditions. Connections may be lost temporarily. There are financial penalties for system failures, so the overall system must be resilient. This requires some level of self-monitoring and self-diagnosis. For example, an optical sensor reads pre-defined pixels on a video screen to ensure human readable output is actually delivered. Incentives must be delivered without perceptible bias, requiring the campaign to be dynamically co-ordinated.

This is a simple example of a Cyber-Physical System. However, the same principle of sensing/actuating (potentially generating large amounts of data) and significant computational ability, can be deployed to add extra capabilities to existing systems, making them more resilient or flexible, gathering useful information or improving efficiency. We present examples throughout this brochure.

Part 2: CPS opportunities & challenges

CPSs can be leveraged in many domains, for many purposes, but there are some common opportunities and challenges that affect CPS design in any domain. This section illustrates some of these common challenges and opportunities by describing CPS projects undertaken by businesses from different domains all around Europe.

Collaborative Design in Embedded Systems

Paper handling equipment

Neopost is an SME based in the Netherlands that manufactures equipment for mail handling. The firm employs around 75 R&D engineers, approximately 50% trained as software engineers and 50% as mechanical engineers. Neopost products include equipment for flexible document packing and automated processing of high volume mail. These involve embedded systems, incorporating both highly precise hardware for picking up and manipulating paper at high speed, as well as software control logic.

Neopost wished to study causes of paper misalignment. Misalignments can lead to collisions between (folded) documents and the envelope to be filled, creating paper jams and a less productive system. Neopost wished to understand how the different causes of misalignment contribute to a collision. This would allow engineers to prioritise where to spend their available design effort. They considered one particular system which has a number of bins containing sheets of paper (e.g., separate printed pages for a multi-page document) and also a bin to hold empty envelopes. It is configurable, picking up separate documents from the bins and folding them in sequence, inserting them into envelopes, sealing them and depositing them into an output bin, at high speed.

In order to understand the causes of paper jams, Neopost invested some time building and analysing models of this system. They particularly concentrated on "collaborative models" that allow the software engineers and the hardware engineers to collaborate at an early design stage. Neopost chose to evaluate the use of a co-modelling tool called Crescendo. This is a "co-simulation engine", developed by the EU-funded FP7 project DESTECS.

Technologies

Modelling is much faster and cheaper than building and testing physical prototypes. This allows a larger number of proposed designs to be analysed and a better-quality system to be built. Typically, hardware is modelled and designed separately from the accompanying control software. The tools, terminology and design techniques used to design hardware and software are not easily integrated. This is because engineers working on hardware design typically model the finished system using continuous-time mathematics, whilst software engineers model software using discrete-event mathematics. Unfortunately, not only are these two modelling techniques difficult to integrate, but neither is ideally suited to take over the function of the other. For example, software models are poor at capturing important timing information required for hardware design, whilst hardware models do not capture aspects which are important to software. As a result, hardware and software design teams usually work separately, with a high risk of misunderstandings and inappropriate assumptions as a result. Many misunderstandings will not be uncovered until hardware and software are brought together at a late stage in the design process.

Crescendo tackles this problem by supporting collaborative design. Each design team –hardware engineers, and software engineers –develop a model using a notation which is natural to them. Then Crescendo executes a joint, collaborative simulation based on the two separate models. Neopost developed co-models using Crescendo to study the problem of misalignment of paper as it is manipulated by the paper-folding and envelope-stuffing system.

Outcomes of the case study

Neopost's modelling activities are not available due to confidentiality reasons. However, Neopost engineers estimated that significant effort was saved due to the ability to analyse the complete system at an early stage, allowing their engineers to identify and solve design problems and save prototyping effort.

Helping engineers and software designers to collaborate early in the design process can reduce development effort, particularly when designing complex interactions between hardware and control logic

Paper handling systems as examples of CPSs

This example focuses on advanced embedded systems which incorporate sensors and actuators to interact with the environment, and software to provide control logic. Like embedded systems, CPSs also involve elements to interact with the real world as well as complex software, and therefore challenges and advances in embedded systems are also relevant for CPSs. A key challenge for CPS engineers is the question of how to tackle design teams working in different disciplines, with incompatible design tools. Allowing them to share design ideas and assumptions at an early stage in the design process can result in faster and cheaper development efforts, with fewer prototyping cycles.

Smart process monitoring

Plastic injection moulding

Pernoud, based in France, specialises in injection moulding tooling for thermoplastic parts, thermosetting parts and composites. Pernoud designs and manufactures injection tooling, which is delivered to plastic producers, together with technical instructions.

The Rhône-Alpes Innovation Hub aims to make improved information available for the mould maker about the production phase, by introducing sensors and an acquisition system in the mould. This “Smart Mould” will store all production information and is a first step towards deploying a complete smart system, an important enabler for the introduction of electrical actuators. Electrical actuators would simplify sliders and suppress the need for a complex hydraulic system in the tool, so achieving this would have major impact.

Smart moulds as examples of CPSs

Pernoud has designed a complete Cyber-Physical Production System (CPPS) provide monitoring and control of the plastic injection mould process. It consists of a control device added to the mould to record environmental sensor data to characterise and monitor the process. This will benefit Pernoud’s customers (plastic part producers) for the tractability, the enhanced production quality and optimised tool maintenance. Monitoring will also enable a transition in maintenance planning, to a conditional maintenance plan instead of a systematic one. In addition, the mould maker will develop improved understanding of how the mould is used, and can then adapt the maintenance operation to suit real production needs.

The purpose is to make the mould “intelligent” - aware of its environment, storing pertinent data and giving meaningful insight to the operators and the mould makers. The mould can analyse captured data about the environment and connected injection machine, and act upon it by e.g., raising alerts or activating actuators.

Technologies

The control device will be developed using a Raspberry PI board (or similar). Planned functionality includes high precision (<0.1mm) electric motors to manage the moulding process itself. The new operating system will rely on ICT technologies, including: supervision, using sensors in the mould; intelligence, embedded in the mould to manage sensors and information; data acquisition, to record and compare information; and communications, to broadcast data.

The Smart Mould itself is a steel mould for manufacturing plastic pieces, which has computation and communication capabilities supporting data exchange standards such as EUROMAPS and OPC-UA. Information can be shared with other manufacturing equipment, therefore the mould participates in the Internet of Things of the factory.

The tools and platform used are those delivered by the BEinCPPS project and its technological actors, such as ITI, ENG. Because this study features a change in the processing steps of Pernoud, an overall modelling approach has been retained to help capture a complete view of the process, including the phases performed in the client premises once the mould is delivered. For this, Pernoud uses CEA's UML-based modelling platform Papyrus.

Expected outcomes of the case study

Adding intelligence embedded in the mould offers new opportunities:

- Paving the way towards a "self-running" mould, featuring full-electric actuators
- Managing the mould thanks to the connected module
- Optimized maintenance
- Increased traceability of the part for the customer

Currently the only link (except for maintenance) between mould makers and plastic producers lies in the directions and advice which is shipped by Pernoud; smart moulds bridge the gap. Smart monitoring can lead to increased life span for equipment, and valuable insights on potential

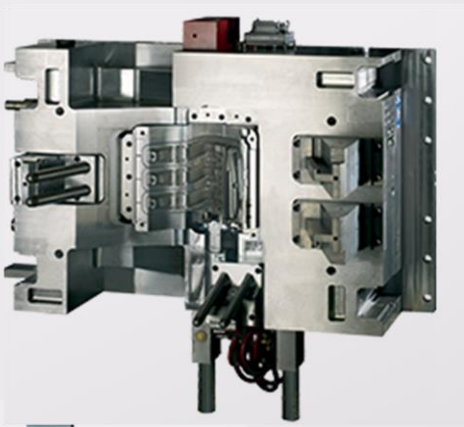
CPS techniques such as smart monitoring and data gathering can produce significant value chain changes, benefiting all players

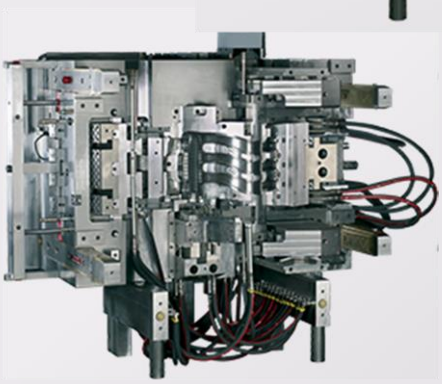
throughput accelerations which could be applied.

Triggering such a numeric transition requires the business to embrace a spirit of innovation and benefits from proper mentorship by a competence centre or innovation hub. Once triggered, the transition offers many subsequent opportunities for business expansions.

Further information

More information is available from www.beincpps.eu/





Steel moulds, and a machine for manipulating them, for producing thermoplastic equipment

Device condition monitoring

Industrial welding

Harms&Wende, based in Germany, produces welding control systems, particularly for pressure resistance welding. Resistance welding equipment is supplied to machine construction companies in the form of control devices, quality assurance systems and complete packages. Welding controls and their sub-components (such as capacitors, fans or thyristors) are affected by wear and tear due to electrical, mechanical or thermal influences, which can lead to a partial or complete control failure. In such cases, the overall equipment effectiveness (OEE) drastically decreases, as production will be stopped until an adequate substitute is available. There's a need for systems to monitor the control's condition in order to predict failures, and provide key performance indicators (KPIs) for assessing wear of the different control's components. This would enable services like maintenance planning and refurbishment planning.

The major challenge is development of a CPS capable of reliably monitoring the welding control condition, without extensive modification of the existing system. The solution must be cheap, but also produce reliable predictions and performance in a real production environment.

Industrial systems as examples of CPSs

Welding controls are complex embedded systems, requiring critical timing behaviour in production. Modifications of live systems (software or hardware updates, etc.) for condition monitoring is usually not practicable. For that reason, a CPS based solution was chosen.

The monitoring CPS is formed from low-cost hardware, running software models for physical and statistical process control. It is equipped with sensors for measuring relevant signals from the welding control and its environment (e.g. temperature, humidity). The physical welding control's behaviour is reflected in a virtual representation within the CPS. An interactive human-machine-interface (HMI) allows for visualization and control of the CPS.

Technologies

The general principles of the CPS for condition monitoring have been worked out within the EU-funded project ReBorn; these principles were re-used. The condition monitoring system has been implemented using a Raspberry Pi 2, equipped with various digital and analogue input and output channels for process data communication. Additional

hardware was used for e. g. wireless data communication, or for large data storage. Specific hardware was developed for welding signal measuring and pre-processing. The system is connected to a software suite ("Workbench") via a REST interface, using web technology. Workbench implements analysis and decision-support tools at systems level – e.g. LCC, LCA or planning factory layout with available equipment.

Outcomes of the case study

The case study shows the potential of CPS for enriching existing production systems. Almost no modification on the existing welding control was required for reliable condition monitoring, which drastically increases the industrial acceptance of such systems.

Access to the CPS via web technology, and smart phones for remote access and control, are very useful. Due to CPU performance and the storage capabilities of the selected hardware, the CPS allows for fast and complex data operation. Presenting this in an accessible and usable way to the user can reduce the training required for operators. The high performance computing on embedded systems allows for data mining and data cross-correlation analysis which supports the implementation of virtual sensors. The monitoring and predictive capabilities of the CPS are very promising, but do need further investigations in a larger extension, with production environments.

Use of off-the-shelf hardware, general purpose operating systems (Linux) and common software programming languages and environments speed up the time-to-market in comparison to non CPS (e.g. traditional PLC or microcontroller systems) tremendously.

CPS technologies allow low-performance or traditional equipment to be upgraded with high-end capabilities, developing systems which are easily extensible

Further information

More information about the ReBorn project and this case study is available from www.reborn-eu-project.org/

Digitally-enabled business models

Manufacturing and production

Manufacturers of production equipment can exploit CPS technologies to develop new value propositions and business models, by expanding and digitising their services and products. Making available information about equipment state and associated process parameters is a key enabler.

The eApps4Production project aims to create a platform making production data available - including real state and process data of CPSs - at any time, at any place and on any end devices. This is achieved via application-specific engineering apps (eApps) - small applications developed for a specific engineering function or domain. eApps produced by different specialists can be deployed to the platform. Examples could include applications for load monitoring, process control or quality management.

For example: MAG IAS, based in Germany, produces tools for metalworking. MAG wishes to provide applications with highly customisable displays for technicians maintaining customers' machinery on site. To address this MAG is developing a configurable tool with CheckMobile, a firm specialising in business process execution and monitoring through mobile devices.

Leitz, also based in Germany, produces machinery and tools for woodworking and is interested in transforming current business models, by adopting modern payment models for sale or rent of tools. Clients could then pay per sawn meter or per drilled hole (for example). Collecting production data makes this possible and also enables optimisations to tool maintenance planning.

Technologies

eApps4Production includes many partners. Web-based technologies have been used to develop platform parts and services. Fraunhofer IPA is developing their own cloud based platform Virtual Fort Knox to provide production-oriented IT solutions for companies from private or hybrid cloud solutions.

The open source container virtualization tool Docker is used to deploy backend services. Services and applications are developed in open source frameworks for Java and NodeJs, due to the popularity, large communities and tools available of these technologies. Data storage is provided by MySQL and MongoDB databases. Communications are built on top of the MTConnect protocol, a popular protocol for tool machines. MTConnect can be easily adapted to OPC UA, which is also a very widespread communication standard.

For the eApps, various approaches have been chosen. For example, pol Solutions has developed adapters to connect machinery using Microsoft Excel's RDP functionality to collect data and visualize or compute information in a format familiar for Excel users. CheckMobile has developed an Android-based application, which can be freely configured by maintenance technicians to visualize relevant information and trigger or execute repair processes. The German firm GPS has developed services to collect live process data and process it in real time, for optimising processes and tool usage. VBMation's vision systems are also in place to detect failures and send out notifications to process engineers who can then take action.

Two solutions have been developed for orchestration of services. Pol Solutions have built a lightweight platform on the open source Node-RED platform by IBM, which allows an easy and cost effective deployment of services and applications. Fraunhofer IPA have developed their own holistic platform, based on the VFK platform, to deploy applications in the form of Docker services, providing monitoring, metering and billing of application usage. This platform can be used to deploy an instance of the Node-RED platform, provided by pol Solutions, allowing for a vendor-agnostic deployment of applications.

Data from varied sources can generate valuable new information and enable use cases and business models not previously possible

Outcomes of the case study

Partners in the project have found the availability of production data useful; in particular, Leitz made new scientific findings in the form of a new method to perform tribological calculation to measure tool wear in woodworking. The new method is based on real time process data collected with the help of micro-services connected to the machines, and learning algorithms to create an exact description of the current tool conditions.

Overall, the eApps model has been found to be expandable. New services can be deployed in the cloud and connected to the machinery to create new functionality which generates valuable new information, and enables use cases not previously possible. All this can be done by connecting equipment - including legacy equipment - to cloud systems which provide additional functionality via micro services to the devices.

Further information

www.eapps4production.de

Integrating touchless interfaces

Surgical environments

TedCas is an SME based in Navarra (Spain). The firm specialises in Human-Macine Interfaces (HMI), particularly for medical domains. This includes hospitals as well as solutions for improving patient recovery through the use of cameras and exercise programs.

Surgical systems as examples of CPSs

Increasingly, technology is employed during surgical procedures, for monitoring and managing the patient's condition, collecting data, improving visualisation of patient data and so on. Many of these systems can be viewed as CPSs, since they rely on distributed sensors to collect information and process the data in real-time.

Sterilisation management represents one of the biggest risks that a hospital has to deal with every day. Maintaining the sterile environment is of utmost importance for all the equipment used during surgery. In this example, TedCas aim to develop interfaces for surgical CPSs which are completely touchless, in order to facilitate sterilisation management.

The development of new low cost embedded systems such as cameras (e.g., Microsoft Kinnect) and motion detectors (e.g., Leap) offer new possibilities for innovative touch-free interfaces that transform the way systems are controlled. Touchless interfaces for the complex systems used in surgery could improve sterilisation management procedures by reducing the need for multiple staff members to touch (and potentially contaminate) complex electronic equipment frequently during surgery. Therefore, widespread adoption of such technologies could improve patient safety.

However, the impact of these generic technologies is hindered by limited interoperability in the medical sector. Innovative new equipment must be integrated carefully into existing surgical systems, which are often complex in their own right, required to be reliable and highly available, and can include legacy equipment. Integration of new equipment in the medical domain can therefore be very limited, or prohibitively expensive.

The TedCas case study therefore addresses two main challenges:

- Evolve the standard human-machine interface used in surgical environments, including evolving the accompanying operational procedures
- Ensure interoperability of the finished solution with existing equipment

Technologies

TedCas began development using Microsoft Kinnect as a key platform. However, after development began, new platforms emerged, similar in price but better suited to the specific application needs. The initial version relies on cameras. A more evolved version of the solution combines the image with data from the LEAP motion sensor and a

Interoperability is one of the main barriers for adoption of disruptive solutions. Strategic partnerships are one strategy that can be used to tackle this

bracelet that increases the accuracy of the movement identification. These improvements were important for ensuring ease of use and user acceptance, both of which are critical success factors for new surgical systems.

Outcomes of the case study

Interoperability is a key requirement to combine new technologies with existing technologies, otherwise the adoption of new equipment become much more difficult. The development of strategic partnerships is a key success factor for the integration and successful adoption of these novel touch-free interfaces into traditionally closed business areas.

The case study will provide a demonstration of improvements which can be produced through CPS adoption, including transforming operational procedures in a traditional sector.

Interoperability in the health environment is difficult to achieve and is one of the main barriers for the implementation and development of disruptive solutions. The partnerships act as a major driver under these circumstances.

Further information

www.tedcas.es

Adaptive measurement intervals for low power sensors

Smart cities

TST, based in Spain, is an SME developing IoT hardware for different domains, including smart cities.

Smart city applications include sensors distributed over large areas, and facilities for analysing the data produced, in order to optimise aspects of city life, such as power, traffic, waste management, air quality etc. The scale which is involved when deploying applications for cities or regions raises challenges - from sensing technologies to data storage and processing. This case study addresses two technology gaps: big data; and sensor battery life.

Smart cities as examples of CPS

Like all CPSs, smart cities involve distributed sensors and significant computation for analysing the data produced. Many smart city sensors rely on batteries for power, as they are not directly connected to a power source. Battery life is therefore an important cost factor.

Making data transmissions consumes significant power. Traditionally, sensors employ fixed-period data reporting. However, it's not always true that performance of the application is improved by frequent data transmissions. In fact, fixed-interval transmission of readings may waste battery life, since the reporting intervals are designed for worst case scenarios, and many sensors may make transmissions that are not necessary.

A possible solution is to design sensors which can adapt to flexible measurement intervals. This would save power and also ensure that the requirements of the smart city applications are always based on real needs.

TST need to present a solution that works, performing and delivering expected results regardless of conditions. The goal is to employ devices which are able to detect that in remote areas a measurement (for example) every two days may be sufficient, but that in densely-populated urban areas, this period may need to be increased to perhaps once an hour as services are consumed more intensively. Sensors should be able to adapt when moved from one zone to the another, identifying and adapting to the new conditions.

TST's project centres on designing sensors which can self-configure. Information provided by the sensors will be analysed to determine the optimal measurement intervals. The reduction of unnecessary transfers saves power and also helps municipalities understand citizens' behaviours by geographic area - useful for optimising services.

Technologies

This requires big data to optimise hardware development. There are number of challenges:

- Ensuring that enough information is obtained (from various sources, including utilities, traffic, etc.) to identify optimal measurement intervals
- Extending the adaptive model through the city
- Producing hardware devices allowing dynamic reconfiguration

The heterogeneous data sources and the analysis affects several domains and different platforms. For data collection and management, the big data platform and data storage NGSI and CKAN format will be used for preparing the data. SIGFOX and Zigbee could be used for telecommunication standard although any communication interface should be permitted in the long-term. PCB size and design would be optimised. Altium will be used for PCB design.

Expected outcomes of the case study

Self-configured hardware will reduce the device costs, both in capital expenditure and operational expenditure. Sensing devices currently available on the market require users to configure sensors manually, requiring either training or a higher device cost.

Dynamic reconfiguration and flexible systems that can adapt to emerging requirements or conditions are a major strength of CPSs

Smart city applications and technologies offer new opportunities. One of the strengths of a CPS is that it can collect environmental data and make adjustments to the current environmental conditions. Devices are needed which are capable of reconfiguring dynamically to deal with newly emerging requirements whilst maintaining a high degree of performance and availability.

Further information

www.tst-sistemas.es/en

CPS socio-technical challenges

Patient recovery monitoring

Mutua Montañesa, based in Spain, provides support for patients suffering or recovering from occupational diseases. Mutua Montañesa are interested in using a variety of systems for monitoring patient progress and reviewing exercise and treatment plans. This can be achieved with non-intrusive wearables and cameras, for example, linked to intelligent processing to analyse the data generated. This would allow medical personnel continuously to monitor the effectiveness of a treatment programme, identify cases where the prescribed exercises are not being carried out correctly, and provide early warning signs of new or exacerbating injuries, for example. However, this case study does not concentrate on the technology challenges of delivering this system but on the socio-technical challenges of deploying a CPS into a new domain. This includes solving privacy aspects and user acceptance of technologies, issues of privacy and invasiveness, accessibility of design, regulatory and ethical frameworks and understanding what the deployment of the devices will imply in terms of data collection.

CPS technologies are capable of bringing improvements and positive impacts to specific areas (such as monitoring patient recovery). However, it's important not to minimise risks or socio-technical aspects. Collecting exhaustive data on all aspects of patient recovery can have a significant impact on the effectiveness of therapies, but on the other hand careful consideration is needed for the invasiveness of the chosen technologies, and all parameters included in the recovery equation must be justifiable.

Case study aims

- Define effective education plans for all the actors that participate in the scenario, from patients to data analysts.
- Control the flow of information to avoid any leaks in the whole chain.
- Fulfil privacy requirements.
- Integration of multiple platforms requires the definition of different layers for smooth, same level interaction

Patient monitoring as examples of CPSs

The case study addresses several socio-technical aspects of CPS design:

User acceptance. Are patients ready for this technology, and are they aware of the impact of their participation? This includes impact on their own recovery, and also the potential to improve subsequent treatments for others. These questions need to be addressed and users must be capable of making informed choices before technology can be deployed.

Selection of the optimal devices. Many CPSs involve adapting commercially available devices "off the shelf". Identifying optimal choices can be difficult. In this case, several tracking devices are available, each with strengths and weaknesses. Each treatment plan requires different accuracy in the measurement, so it can be difficult to elicit requirements.

Integration of collected data. How to merge information generated from different vendors with different hardware and different platforms?

Data storage and privacy. Integration of heterogeneous sources of data is only the first step of data exploitation. A framework is also required for properly storing all the information, maintaining compliance with relevant regulations and enabling access for processing.

Data analysis. Requirements for data preparation to apply techniques to extract the full potential of the data.

There are very similar challenges to face in the deployment of CPS technologies in a range of application domains – these challenges are not only relevant to medicine. It's important to develop a solution from a holistic point of view.

Education of users is as important as technology accuracy for the effective deployment of CPS in a given domain

Expected outcomes of the case study

This case study illustrates some challenges to solve in order to transform an application domain and facilitate the adoption of CPSs. It combines technical and non-technical aspects. Solving these challenges to develop a holistic solution that fully satisfies the requirements of regulators, patients, clients, and medical practitioners will enable the adoption of CPS technologies which are capable of delivering significant improvements in the domain, including improved outcomes and quality of life for patients.

Key Lessons

Education of users is as important as technology accuracy for the effective deployment of CPS in a certain domain.

Interoperability becomes a real challenge when trying to combine different solutions provided by different stakeholders.

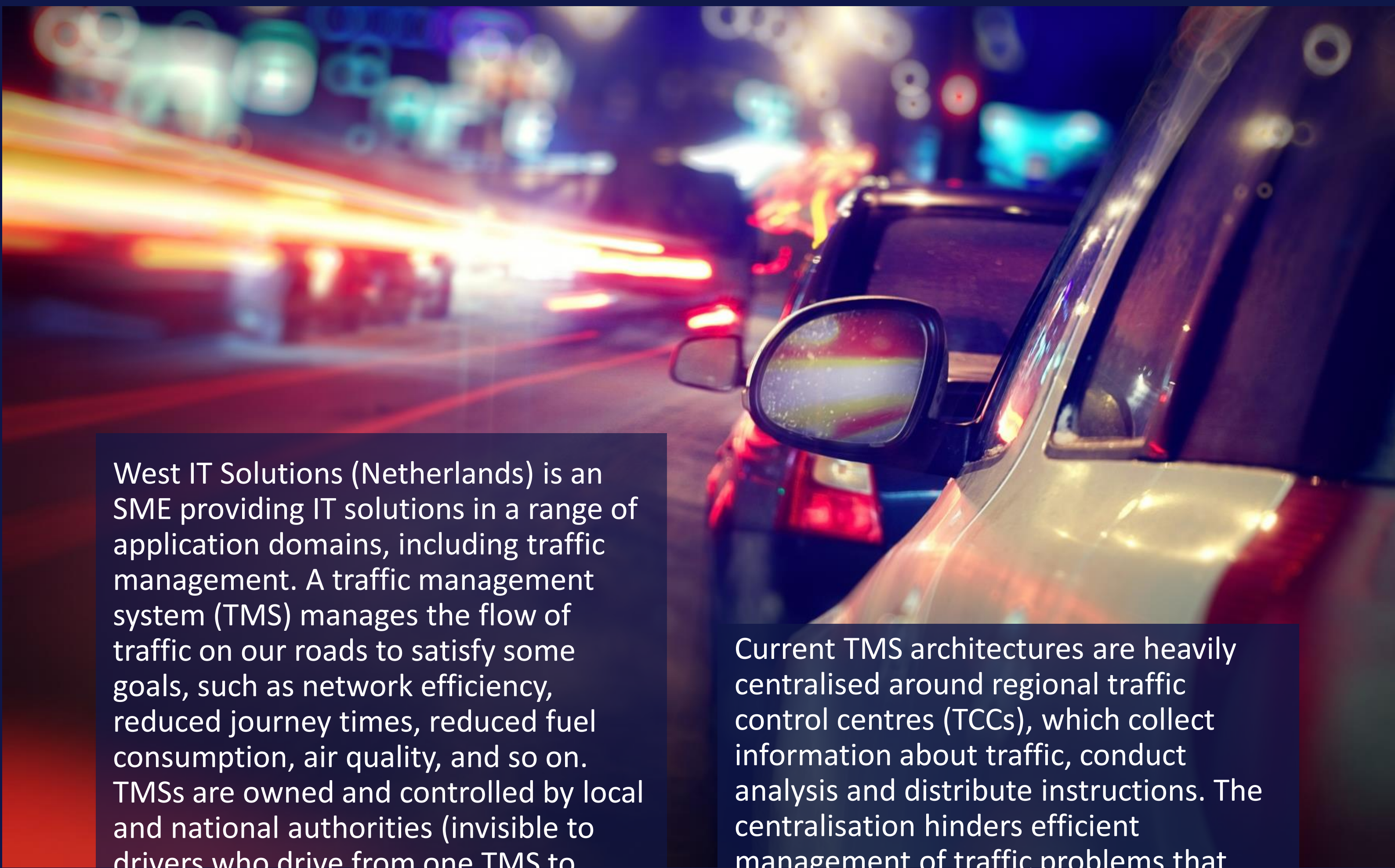
Regulatory frameworks in many domains that can exploit CPS impose requirements that must be considered also, not only for the penalties but also as key driver of the CPS industry in Europe.

Further information

www.mutuamontanesa.es/web/

Distributed control architectures

Traffic management



West IT Solutions (Netherlands) is an SME providing IT solutions in a range of application domains, including traffic management. A traffic management system (TMS) manages the flow of traffic on our roads to satisfy some goals, such as network efficiency, reduced journey times, reduced fuel consumption, air quality, and so on. TMSs are owned and controlled by local and national authorities (invisible to drivers who drive from one TMS to another freely). Traffic is managed via devices installed roadside. These may be sensors to monitor traffic, or actuators to influence its behaviour – for example, by controlling traffic lights, displaying messages, changing configurable speed limits or opening and closing dynamic lanes.

TMSs are often required to mitigate the effects of unplanned incidents – such as vehicle collisions, floods or road blockages. Sometimes these incidents occur at or close to the boundary of a TMS region, and the effects may be felt in the neighbouring TMS region also, operated by a different authority.

Current TMS architectures are heavily centralised around regional traffic control centres (TCCs), which collect information about traffic, conduct analysis and distribute instructions. The centralisation hinders efficient management of traffic problems that straddle boundaries between TMSs, because the roadside devices on either side of the boundary, owned and operated by separate authorities, cannot communicate directly across the border. Instead the separate TCCs must identify the local problem and communicate.

To address this issue, West led a project called TEMPO ("TMS Experiment with Mobility in the Physical world using Overture"). They used rigorous modelling techniques to demonstrate the value of a TMS solution controlled by distributed CPSs. The modelling techniques are designed to analyse the behaviour of interacting software

Modelling techniques can be used on software (as well as on hardware) to analyse a complex solution and adjust the design

components and demonstrated how devices owned by two separate TMSs could interact via automated negotiation processes, including across the border, without waiting for the two regional TCCs to identify the problem and initiate a collaboration. This allows two TMSs to collaborate in selecting the traffic control measures best suited for the traffic network as a whole, including mitigating the effects of incidents felt in two neighbouring regions. TEMPO also implemented new visualisation techniques to illustrate the models in an approachable way. The finished models and visualisations allowed engineers to confirm that key resilience and safety requirements can be met by the proposed distributed architecture.

TMSs as examples of CPSs

Computer-based modelling techniques are extremely valuable for CPSs, as they allow an engineer to test and examine a proposed complex design before committing to building an expensive prototype. Although engineers are familiar with techniques for modelling hardware, TEMPO uses techniques traditionally used for modelling software to analyse the dynamic behaviour of distributed roadside devices.

The goal of evolving centralised control into distributed control architectures is a common goal for many CPSs. Distributed architectures can enable improved performance, resilience and scalability. Key challenges are the problems of ensuring that a system controlled by distributed devices can still guarantee reliable global behaviour, such as fault tolerance or availability.

Technologies

TEMPO used a tool called Overture to model existing traffic management networks. Overture is a tool that supports modelling in *VDM*, which is a well-established method for modelling software. It supports a wide range of analysis techniques, which can be used to identify poor system specifications or to provide confidence in a proposed design. VDM has a strong record of industrial application, often by practitioners with no expertise in the underlying formalism or logic.

Outcomes of the case study

TEMPO provided a demonstration of the value and feasibility of a distributed architecture for a TMS. This forms a basis for new approaches to traffic management and could facilitate the introduction of cooperative and autonomous vehicles in the future without compromising safety or network robustness. Improvements in the management of traffic have direct impacts on commerce and on the environment, allowing TMSs to provide road users with increasingly reliable journey times.

Further information

Available via the TEMPO website http://tempoproject.eu/

Part 3: Applying CPS engineering principles

Smart tourism

CPS technologies can benefit you in your business, by allowing you to create "smart", digitally-enabled systems that collect and make use of detailed data which can be used to improve performance or maintenance, or using actuators to take some actions. In this case study we illustrate how you might consider exploiting CPS technologies in your own field, by presenting a case study of two SMEs applying CPS technologies to an emerging area: smart tourism.

AnySolution S.L. is an SME, based in Spain, offering IoT solutions for building access and security. One product they've developed is a building security system called IoT SmartLock.

AnySolution has traditionally worked on Smart Cities applications. However, whilst developing IoT SmartLock and analysing the market, tourism began to emerge as a new and interesting domain for the company's "smart" products. For example, the hotel industry has significant interest in security and access systems. Hotels also have significant interest in energy conservation; they account for a significant amount of energy consumed by buildings. AnySolution have therefore found an opportunity and embarked on a collaborative project to improve hotel security and sustainability, by linking hotel access systems to energy efficiency and temperature control systems to help to make hotels more sustainable.

AnySolution's partner is ModoSmart S.L., an SME based in Spain that provides IoT solutions to ensure comfort and energy conservation in homes and buildings. Together, AnySolution and ModoSmart will develop a product that directly links the security access system of a room or building security with energy efficiency systems. The system can be easily adapted to any kind of building.

This case study addresses a lack of synchronisation between different systems – building access and energy efficiency – which prevents suppliers from anticipating demand. Opportunities for potential energy savings or security improvements are missed, resulting in a waste of energy and decreased security while hoteliers have little to no access to data describing customer needs.

Technologies

The proposed system will incorporate sensors and actuators connected with AnySolution's IoT SmartLock (a hardware device), managed by a cloud based platform. The cloud-based management system incorporates different requested features and will allow the system to be tailored for each individual building. Different kinds of sensors need to communicate for the complete system, following a specified control logic.

Smart tourism applications as examples of CPSs

Here, we address some of the common CPS challenges already presented and discuss how they impact this case study.

Engineers working on different independent (but interdependent) systems in the tourism sector do not have an integrated vision of the whole system. The proposed solution will demonstrate the positive aspects of incorporating views of different types of system. Collaborations between disciplines were also illustrated in other case studies; for example, see page 6.

Interoperability is a key challenge, since few of the systems and businesses in the tourism sector have been designed with interoperability and data sharing in mind. There are few common data models, for example, to enable data sharing. Interoperability is a common challenge in CPS engineering – for example, see pages 12 and 14. IoT SmartLock uses FIWARE, an open standard platform. This enables easy extensions with additional features in the future, and since FIWARE is well-known, will facilitate interoperability.

IoT SmartLock needs to interact with other systems. Modelling and simulation tools can be very useful here to test the proposed integrations, and increasing confidence that systems will behave as expected. Modelling can also ensure that building-specific requirements can be met. Modelling and simulation challenges are a common theme for many domains in CPS engineering – for example, see pages 6 or 20.

Many CPS applications exploit the ability to identify and react intelligently to changing local requirements (such as different contexts within the building, or between different buildings). AnySolution and ModoSmart could consider this functionality in the future. This is a common goal for many domains - for example, see page 16.

Expected outcomes of the case study

IoT SmartLock is still under development. A pilot is being defined to provide specific, tailored features for a specific hotel. The intersection of domains such as energy, smart cities and security allows efficiency savings, resulting in reduced costs.

Further information

For more information on FIWARE please visit www.fiware.org. For more on IoT SmartLock please go to www.anysolution.eu

Further information

Find further information about any of these case studies from the following sources.

Collaborative design for paper folding equipment

The case study described here was completed as part of the EU-funded DESTECS project. More information is available from *Collaborative Design for Embedded Systems: Co-modelling and co-simulation* (a book by J Fitzgerald,PG Larsen, M Verhoef), published by Springer-Verlag, Berlin. 2014.

Smart process monitoring in plastic injection moulding

This study is an ongoing pilot case in the H2020 BEinCPPS I4MS project: http://www.beincpps.eu/

Device condition monitoring in industrial welding

This case study is a summary of an internal report (D5.4) from the EU-funded FP7 project ReBorn: www.reborn-eu-project.org/

Digitally-enabled business models for manufacturing and production

This case study is a summary of an ongoing national joint project funded by the German Federal Ministry of Education and Research (BMBF). More information available from: www.eapps4production.de

Touchless interfaces for surgical environments

This case study presents a business developed by TedCas: www.tedcas.es

Adaptive measurement intervals for low power sensors in mart cities

This case study presents a business case developed by TST: www.tst-sistemas.es/en

Socio-technical challenges in patient recovery monitoring

This case study presents challenges described by Mutua Montañesa: www.mutuamontanesa.es

Distributed control architectures in traffic management

More details can be found at www.tempoproject.eu.

This case study presents an experiment funded by the EU-supported CPSE Labs project: www.cpse-labs.eu.

Part of EU-funded Smart Anything Everywhere Initiative: www.smartanythingeverywhere.eu

Applying CPS engineering in smart tourism

This case study arises from a project submitted by AnySolution and financed by Fi-PPP FIWARE together with a proposal submitted by AnySolution and ModoSmart complementing the previous project. IoT SmartLock was passed under the SOULFI accelerator, in the field of SmartCities.

For more information on FIWARE: www.fiware.org

IoT SmartLock: www.anysolution.eu

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