MEETING REPORT

August 2017 Newsletter Additions in Red

Sandpit Workshop - Real-time State and Performance from IPT Data for Process Control

The ISIPT *Focussed Symposium* series FSIPT-17-1 Workshop was held at the Kensington Campus of Imperial College, London, UK on 19-20 April 2017 with 17 attendees.

A. Technical Programme

The Programme consisted of 4 sessions, 3 Technical sessions and a final session addressing Collaborative Opportunities. Technical Sessions 1 and 2 were on Day 1 (19 April); Technical Session 3 occupied most of Day 2 (20 April) followed by the brief Session 4.

SESSION 1 - Objectives and Process Control Foundations

Objectives of workshop and foundations of Advanced Process Control (APC) in terms of commonly applied variant Model Predictive Control (MPC).

Presentations:-

Workshop Aims and Objectives: Brian Hoyle (ISIPT)

Overview of MPC: Jonathan Love (Imperial College)

MPC Opportunities, a User's Perspective: Sean Goodhard (BP)

Current Generation MPC Technology: Geoff Lewis (Schneider)

The session began with a brief introduction to the technology and 'state of the art' of IPT, specifically to indicate a general foundation of sensing and instrumentation capability for attendees having little IPT experience; followed by a review of the Workshop Objectives.

As implied in the Workshop title the overriding objective was to explore new opportunities to incorporate IPT data into process control. To date applications focus mainly upon *process understanding* in a pilot plant or laboratory setting. The intention here was an exploration stressing application benefit and recognising that deployment of IPT technology will cost, and hence must deliver increased information that delivers proportional process benefit.

The Workshop format was designed to separate the exploration into a progressive set of sessions. These were prioritised to explore opportunities and benefits together first, with a later consideration of technical viability; i.e. an *application-pull* rather than a *technology-push* approach. Below for convenience we report the integrated results of these sequential exploration rather than the results of each part.

This was followed by a three-part introduction to the 'state of the art' of advanced process control. The three viewpoints: fundamentals of 'Advanced Process Control'; applications focus by major user BP; and, system capabilities from major supplier, Schneider.

These provided a very authoritative platform ideally suited to inform later discussions.

SESSION 2 – Opportunities and Benefits

Explore routes to a methodology to seek effective process opportunities; scope and scale process operations and multidimensional sensing benefits

Session introduction: Processes and Sensing Opportunities: Brian Hoyle (ISIPT)

This provided a short list of the various sectors in which there have applications of IPT to date. This was followed by a generic review of the features of a process that are typically of interest in terms of the predominant motion of materials; their phase composition and a proposed classification (purely for this purpose) of major process types. An example was shown, featuring a process mixer, of how IPT *reality visualisation* data was converted and extracted from the data rich image sequence to yield process performance information.

Much of the following part of the session was devoted to plenary group discussion, group breakouts and following reports. It began with an overview plenary discussion:-

Plenary discussion – Processes, Needs and IPT Benefits

The discussion explored some common points about 'single-point' sensors and the IPT 'multi-dimensional sensing' (with its attendant need for 'interpretation'). If control is based upon a single point - is a resulting 'optimal' the best possible optimal...? It was noted that to be useful more complex sensing must deliver process benefits.

This was followed by breakout session based upon 3 Groups, each having about 4 members. The Groups were asked to consider specific process sectors:-

Group I Chemicals, FMCG, Pharmaceuticals

Group II Environmental, Nuclear, Automotive

Group III Oil and Gas, Minerals processing

In Session 2 there were 2 breakout sessions:-

Breakout 2A - 3 Groups classified by process sector

Each group will explore a set of example sectors and identify possible benefits of increased multi-dimensional data in control and:-

Breakout 2B - 3 Groups by 3 contrasting applications

Each group will explore one promising selected exemplar in terms of the challenges to be addressed to deliver useful process information.

As noted above, composite results are presented together below.

SESSION 3 – System Realisation

Explore steps to realise promising applications – identify challenges and routes to solutions: common architectures, data design, generic algorithms, inverse reconstruction, feature identification, model parameter extraction and integration with wider system requirements.

Session Introduction: Architectures to Deliver Process Information: Brian Hoyle (ISIPT)

This review began with the reported Leonardo da Vinci proclamation: *Simplicity is the ultimate sophistication*, interpreted as discussed above, but in a more technical context as: *adding IPT will add complexity - will this be justified in terms of value of better insight*?

The review outlined the application types and their *information requirements* in terms of how IPT would function, and critically how image data would be *transformed* to useful process information. A set of principles were proposed for a methodology for the corresponding design of simplest IPT sensing approach. A classification of IPT instrumentation types was suggested to describe layers of capability. For example, from a *1st generation* instrument that can fulfil sensing needs in processes that exhibit a clear variation of an IPT detectable property (e.g. electrical conductivity, or X-ray attenuation) where this provides raw image data that can be transformed to useful information (e.g. batch process stage, or an optimal state for a continuous process). More complex *2nd generation* systems were illustrated able to address multi-component processes featuring multiple materials or widely changing states. An example was presented of a highly simplified IPT sensor that delivered satisfactory mixing data, used to validate the selection of optimal process equipment, saving energy and material, and increasing product quality.

Plenary discussion – Challenges and Routes to Solutions

Breakout 3 - 3 Groups, as previous day – address selected applications

The original plan was:-

Each group will explore delivery of useful data for ALL 3 selected promising applications.

However, since the groups had worked together effectively on their selected application we diverged to ask Group to explore the realisation of their 'own' promising suggestions.

B. Workshop Results

The 3 groups worked together well and intentionally were mixed in terms of experience and background (as much as member profiles allowed). Group discussions augmented and refined suggestions

Here we present the major conclusions of the three groups with the added augmentation from group discussions.

Group I Chemicals, FMCG, Pharmaceuticals

Chemicals Sector-1 - Enhanced monitoring and control of pressure filter process

Opportunity-1: Pressure filters are critical in manufacture of many chemicals. An opportunity to enhance performance (with multiple benefits) would be to monitor flow distribution through the filter cake. There is a tendency for channel forming - which degrades performance and in the extreme may caused a batch to be aborted. The process is typically a liquid flowing through a permeable solid.

Benefit-1: On-line monitoring could deliver information usable for control of pressure (controlling channelling) reducing outage and waste and increasing production and quality.

Realisation-1: Requirement would be to monitor the filter cake profile to 'view' the flow trend. Control the time and pressure in order to minimize pressure drop for filtering chemicals. Monitor moisture distribution, interpret to identify onset of channelling, control pressure to influence state.

FMCG Sector-1 - Monitor bulk food products manufacture - including regulatory requirements

Opportunity-1: Many FMCG processes have limits on specific ingredients, E.g. margarine water content may be limited, but may advantageous to manufacture product that is near the limit, e.g. for moisture distribution (”to sell as much water as possible!”). In other product control of drying, bulk density may be critical.

Benefit-1: Measurement of moisture in ’spreading fat’ type products; and in powder products such as milk powder.

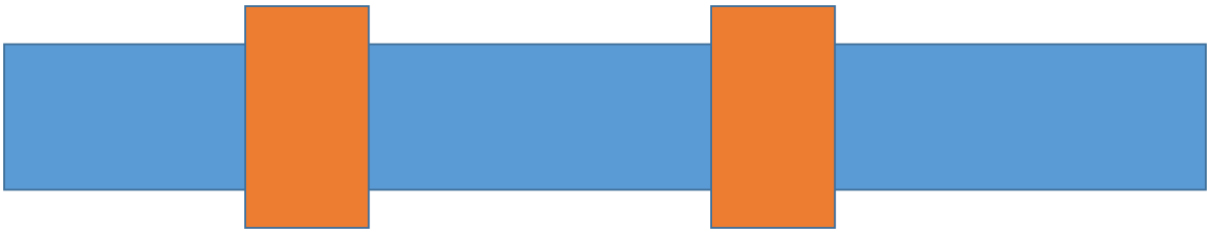
Precise recipe control verfication on soft foods and liquid products, e.g. baby food, yoghurts

Parameters to measure: consistency, composition (average) and also locate and reject foreign bodies.

Realisation-1: ERT/ECT/multimodal measurements sequentially; two planes/3D, possibly differences between the planes

Calibration of measured quantity to the desired parameters

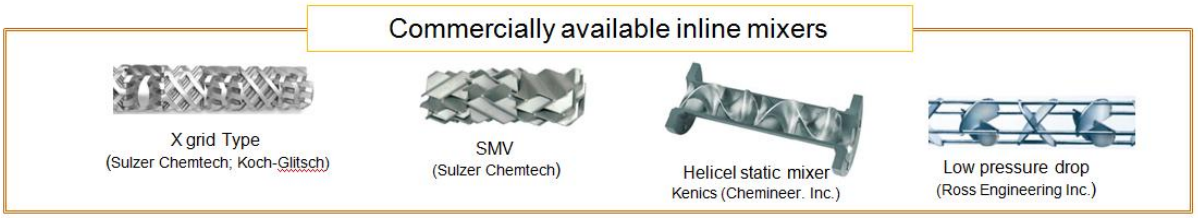
Support for active control of critical paramters



FMCG Sector-2 - Enhanced Control of In-line mixing

Opportunity-2: In-line monitoring/control of food products; general Quality Assurance.

A key technique explored in some depth was ’in-line’ mixing; several products, e.g:-

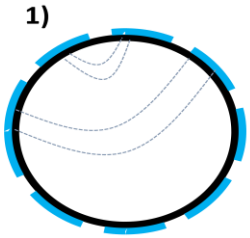


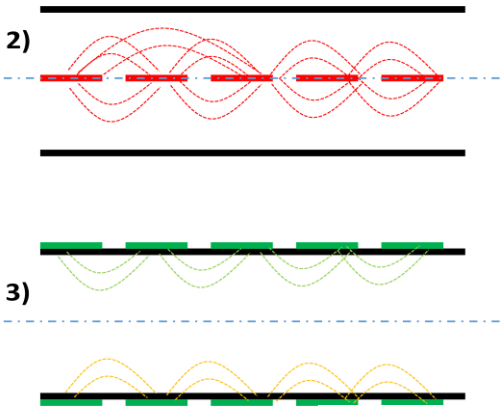
These are used in ’fixed length’ segments - several stages are typically placed in series (but each stage incurs pumping costs).

Benefit-2: Enhance **c**ontrol to gain optimal inline mixing (low pressure drop, highest homogeneity) of mixtures in a pipe, perhaps through stage-end, or distributed sensing. This provides information that could be used for control.

Realisation-2: Wide ranging possibilities reviewed to suit many application types:-

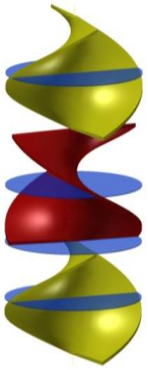
Sensor topology could be conventionally arranged in cross-sectional groups between stages but could also be field-focussed (1); distributed linear core (2); or peripheral (3) sensors, as illustrated:-





Data Needed may be:
Water content distribution in the cross-section; Total volumetric water content (water cut), Composition (species tomography);
Average value / Variance (Std Dev)

Control variable(s) could be: Water flow rate (air flow rate); Number of mixing stages / mixer blade position/angle, as illustrated alongside



Signal conditioning may be: Coded excitation, time and frequency filtering using wideband signals (electrical); Modulation (optical signal), photon density wave measurement is also possible

Potential measurement/tomography techniques (to suit materials):-

ultrasound (clamp-on)	sound impedance
electrical (ECT/ERT)	water content, possibly spectro-tomography
microwave	water content
optical diffusion	scattering properties,
VIS/NIR	spectro-tomography

<u>Pharmaceuticals Sector-1 - enhanced product monitoring and manufacture</u>

Opportunity-1: Transition from batch to continuous manufacture through process monitoring through to tablet manufacture

Benefit-1: Improved monitoring of mixing of raw materials, homogeneity

Improved granulation, control duration, speed

Quality control of final product (pin holes, cracks?)

Realisation-1: Method to detect pin holes, cracks: miniature tomography, ultrasound.

Group II Environmental, Nuclear, Automotive

<u>Environmental Sector-1 - enhancements by improved monitoring</u>

Opportunities-1 (several 'treatments' outlined):

Waste water treatment (oxygen supply/bio-reaction yield);
Moisture/nutrient soil (agri-production, greenhouses);
CO2 capture by amine scrubbing (column operation);
Temperature profiles in solar salt storages (mixing, solidification, thermal efficiency); health monitoring of batteries and fuel cells.

Benefits-1: Better monitoring gives improved control to drive down pollutions etc

Realisations-1: Very dependent upon application.

Environmental Sector-2 - enhancements by reducing emissions

Opportunities-2: Monitor/enhance combustion efficiency in IC Engines; Furnaces, Boilers, Fluidized bed combustion; Coal-fired power plants.

Benefits-2: Better information and control can drive up efficiency and drive down emissions.

Realisations-2: Very dependent upon application.

Nuclear Sector-1 Enhance safety and efficiency

Opportunities-1: Wide range of processes:-

Fuel processing/reprocessing (→ part of Chem Eng Technologies) - extraction, precipitation, centrifugal separation, electrochemical processes;

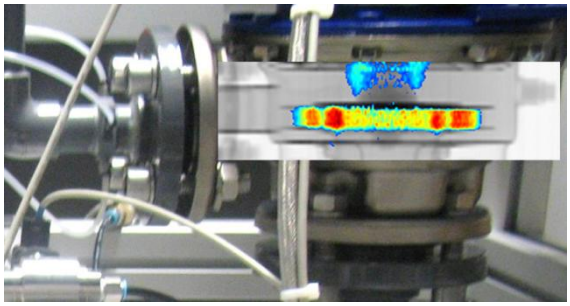
Cavitation and gas entrainment in emergency pumps (speed control, degassing);

Core melt monitoring for severe accidents (cooling/reflooding);

Plasma control in fusion reactors (plasma stability);

Liquid sodium reactors (flow, temperature);

Pebble bed and gas cooled fast reactors (hot spots).



Benefits-1: Better information would enhance process knowledge and hence safety and effectiveness of process.

Realisation-1: Very dependent upon application.

Automotive Sector-1 - embedded sensing for increased efficiency and performance

Opportunities-1: #
Catalyst / emission control;
In-cylinder combustion control;
Lubricant distribution and quality in motor and gear boxes
Hydraulics systems control;
Air conditioning systems (two-phase flow);
Range detection techniques in autonomous driving, e.g. Radar and Lidar..;
Benefits-1: Enhanced efficiency and performance.

Realisations-1: Dependent upon application but embedded, low-cost capability and miniaturised implementation common to all requirements

Group III - Oil and Gas, Minerals processing.

The group explored a wide range of candidate applications:-

Possible Applications	Problems	Variable
Distillation Columns Reactors Heaters	Channelling trough packing Location of the Hot Spot Failures of rings Tube-Skin Temperatures	Differential Temperature Differential Pressure / Fluid Density
Hydro reactor	Process control	Nitrogen Slip
Pipes in refineries	Failures of critical components	Corrosion Detection Wall Thickness
Catalytic Cracking	Deactivation in the catalytic process	Amount of Coke formation
Oil-Saline Water mixture	Measurement of phase fraction in presence of saline species	Density Viscosity (Real Variables)
Mixing & Blending	Energy Optimisation	Mixture Homogeneity Density Viscosity
Sampling	Representative Sampling Phase Fraction	Concentration Distribution
Flowmeter Correction	Liquid-liquid flow dynamics	Material Properties Density Water cut
Multiphase metering	Percentage of 3 phases	Velocity Density Flowrate

These were grouped considering common process characteristics and ranked regarding the impact that addressing the problem would have in the corresponding sector (with other considerations account for feasibility, novelty, industrial interest for applicability):-

1) Mixing/Blending and Sampling – Concentration Distribution
2) Corrosion Monitoring / Flow Assurance (salt build-up, hydrates and scale formation, wax and asphaltenes' precipitation, etc.)
3) Flow monitoring of complex mixtures (Velocity / Mass ratio)
4) Temperature distribution in columns and reactors (track of the Hot Spot)

In the plenary session, it was also agreed that the following mineral processes may have a significant impact in their respective sector:

a) Glass Flow
b) Cement Kilns
c) Sand Detection

<u>Oil and Gas Sector-1 - enhanced monitoring of batch Mixing/Blending and Sampling processes</u>

Opportunities-1

System Output	Concentration Profile Outlet stream parameters (Density, Viscosity)
Location of the monitoring system	a) Perimetric around the vessel b) Longitudinal Section c) Outlet stream
Input for Control	Inlet streams parameters

	(Density, Viscosity, Flowrate)
Control Mechanism	a) Mixing time to meet a target value b) Mixer Mechanism to meet a target value in a set time
Resolution need	Spatial Resolution, Time Resolution
Complexity	a) Spatial averaging (perimetric system) b) Symmetry of vessels (Longitudinal system)

Benefits-1: Optimisation and energy control

Realisation-1: Very dependent upon application - the type of technology, sensor array and even the configuration (multimodal/multi-energy) will vary regarding the species to be observed. It is important to note that in a mixing process non intrusiveness may not be a critical issue, so for example wire-mesh sensors may be easily deployed.

Oil and Gas Sector-2 - enhanced monitoring of in-line Mixing/Blending and Sampling processes

Opportunities-2:

System Output	Concentration Profile - Fluid's parameters (Density, Viscosity)
Location of the monitoring system	a) Perimetric around the pipe
Input for Control	Upstream parameters (Density, Viscosity, Flowrate)
Control Mechanism	Upstream flow to meet a target value (provided that the mixing device is fixed)
Resolution need	Spatial Resolution
Complexity	Sensor temporal averaging

Benefits-2: Optimisation and energy control

Realisation-2: Very dependent upon application - the type of technology, sensor array and even the configuration (multimodal/multi-energy) will vary regarding the species to be observed. It is important to note that in a mixing process non intrusiveness may not be a critical issue, so for example wire-mesh sensors may be easily deployed.

Generic directions

While applications in specific sectors are clearly valuable the closing plenary discussion reviewed the important point that to gain wide ranging success, tomography based sensors must be available as *off-the shelf* products, otherwise the technology will never be seen as anything other than niche or specialist. A general purpose tomography product was suggested with the features:-

- a single unit of relatively short length, perhaps available in two pipeline sizes (say 4cm and 10 cm diameter), supplied with flanges at either end for installing in a pipeline as per a control valve or an electromagnetic flow meter.
- physically robust for plant life, perhaps a mild steel body with a PTFE liner, satisfying IS, IP requirements etc, with configurable parts/components for ease of manufacture, maintenance and repair. Cost is not necessarily an issue.
- must be non-invasive and easy to clean/sterilise for food/pharmas applications.
- two planes of detection, close to either end, which would enable parameters measured in one plane to be verified by the other, an interesting variant noted could include an in-line mixer between the two planes.

- two sensing modes at each plane (e.g. capacitance and resistance) to provide wide ranging material detection.
- focus on measurements of i) consistency (images) in a radial direction, ii) average value of bulk physical properties across the plane, iii) flow rate in an axial direction, and iv) especially for food applications - foreign body detection.
- depending on what is being measured, a standard unit would provide one or more inputs to a DCS and become part of the platform for process monitoring, control (advanced or otherwise), management information, etc.
- Unit menu based software for selection of modes, calibration, display options, etc.
- Develop in association with an established instrumentation manufacturer (e.g. of magnetic flow meters) or even in-line mixer manufacturer to explore options.

C. Collaboration Opportunities

Identify teams and resources to deliver benefits and solutions

Plenary discussion - building teams for applications

At the discussion there was a strong interest in ongoing links to advance the concepts and ideas that arose in the various sessions. It was suggested and agreed that as a first step all attendees would be invited to express their interest in sharing future developments. TWO groups are suggested:-

Active List – Attendees who elect to join this list will receive the email addresses of all other 'active' list members to allow the direct sharing of information with any and all members.

Update list – Attendees who elect to join this list will not have their email addresses released but will be sent a 'progress update' email approximately every half-year (or if exceptional event occurs).

Attendees will be invited to select one of the lists. Those who do not request to join a list will receive this Report but no other contact.

Newsletter Update - if you were unable to attend (or have not yet joined) and would like to join either of these lists - please email: events@isipt.org - with the Subject: **Join List - FSIPT-17-1** - stating in the email which of the above lists you would like to join.

International Society for Industrial Process Tomography (ISIPT)

The workshop was mounted for members of the ISIPT, a not for profit organisation to support all who have an interest in IPT technology and its applications.

If you are NOT a member of ISIPT please consider joining; it is free and simple to join and there is no subscription, visit: www.isipt.org and select the Members link. The minor costs of ISIPT, solely for its small website operations, are funded by small contributions from not for profit events. See the Governance link for more details.

You will ONLY receive information about IPT technology and events - typically a few emails per year. Your details will not be passed to any other organisation.