SUPSI Medical Devices Research Group

Advanced Microfluidic Technologies and Organ-on-Chip Platforms for Complex Biological Models

The first research line focuses on the development of advanced microfluidic platforms for the culture, stimulation, and analysis of complex biological systems. The increasing need for experimental models that more accurately reproduce human physiology has driven the emergence of Organ-on-Chip technologies, capable of recreating key functional, mechanical, and biochemical aspects of tissues and organs within highly controlled miniaturized environments.

Within this context, the group develops innovative experimental platforms that integrate microfluidics, environmental control, sensing technologies, and data acquisition into a single technological ecosystem. The objective is not merely to create devices for cell culture, but rather to build intelligent experimental infrastructures capable of generating continuous, high-content biological information.

One of the main challenges addressed by the group is the maintenance of stable and reproducible experimental conditions over extended periods of time. To this end, the group has developed an architecture based on independent miniaturized incubation chambers, each equipped with dedicated systems for controlling temperature, humidity, gas composition, and microfluidic flow. This approach enables multiple experiments to be performed simultaneously while maintaining fully autonomous and controlled conditions for each biological model.

The developed platforms integrate disposable microfluidic circuits fabricated from advanced materials such as SiO_2 and PDMS, compatible with dynamic cell cultures and biomedical applications. The modular architecture allows easy adaptation of the experimental configuration to different biological requirements, enabling the investigation of various cell types, tissues, and complex biological models.

A distinctive feature of this research activity is the integration of sensing and observation systems directly within the experimental platform. Bioimpedance sensors, optical systems, microscopy modules, and environmental monitoring devices allow continuous and non-invasive observation of cell cultures throughout the entire experimental process. This approach eliminates the need to interrupt experiments for external measurements, preserving the integrity of the biological system while generating longitudinal datasets of high scientific value.

Applications of these technologies range from regenerative medicine and drug development to toxicology and personalized medicine. Furthermore, these platforms provide a technological foundation for future developments in biological Digital Twins, automated drug screening, and advanced disease modelling systems.

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Microfluidic Diagnostic Technologies and Biosensors for Precision Medicine

The second research line focuses on the development of innovative diagnostic technologies based on the integration of biosensors, microfluidics, embedded electronics, and advanced optical and electrochemical detection systems. The objective is to develop miniaturized diagnostic devices capable of providing rapid, accurate, and quantitative results directly at the point of care, reducing dependence on centralized laboratory infrastructures.

The growing demand for accessible and rapid diagnostics, highlighted by recent global health emergencies, has demonstrated the importance of developing new generations of Point-of-Care systems that combine high analytical performance with ease of use and cost-effectiveness. In this context, the group develops Lab-on-Chip platforms that integrate all diagnostic steps within a single miniaturized device, including sample preparation, biological processing, signal detection, and result interpretation.

Research activities encompass the development of DNA-based molecular biosensors, electrochemical sensors, bioimpedance systems, optical detectors, and multimodal platforms for the identification of biomarkers in biological fluids. The pursued approach combines multiple measurement techniques within the same device, thereby increasing diagnostic sensitivity, specificity, and robustness.

A major research area concerns the molecular diagnosis of infectious diseases through fully integrated microfluidic platforms. In previous projects, the group developed portable devices capable of directly detecting viral RNA in saliva samples through the combined use of DNA biosensors, bioimpedance measurements, and fluorescence detection, eliminating the need for conventional PCR amplification steps.

Building upon this expertise, the group is currently involved in the SNSF-SMILE project, aimed at developing a Lab-on-Chip device for the multiplex diagnosis of paediatric respiratory infections using saliva samples. The platform integrates molecular biosensors, advanced microfluidic circuits, automated fluid handling systems, and multimodal detection technologies capable of simultaneously identifying multiple respiratory viruses responsible for lower respiratory tract infections in children.

From a technological perspective, the system incorporates sample pre-treatment chambers, dedicated screening chambers, miniaturized micropumps, functionalized biosensors, and integrated optoelectronic systems for data acquisition and analysis. The ultimate goal is to deliver diagnostic devices that can be deployed not only in hospitals and clinical laboratories but also in resource-limited settings, thereby improving access to diagnostics and supporting epidemiological surveillance and preventive medicine strategies.

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Digital Biomarkers and Quantitative Human Movement Analysis

The third research line investigates human movement as a quantitative biomarker of neuromuscular system function. The objective is to develop methodologies and technologies capable of transforming movement from a qualitative clinical observation into a source of measurable, reproducible, and clinically meaningful information.

Many neurological and neuromuscular disorders initially manifest through subtle alterations in movement that are difficult to identify using traditional clinical assessments. Similarly, ageing processes, functional recovery, motor adaptation, and athletic training induce progressive changes that require more sensitive and continuous monitoring tools. Within this framework, the group considers movement as a privileged window into the functional state of the neuromuscular system.

Research activities rely on the development of multimodal platforms combining high-density surface electromyography (HD-sEMG), inertial measurement units (IMUs), embedded systems, and advanced signal processing algorithms. The synchronized acquisition of muscular and kinematic information enables a detailed and multidimensional characterization of human motor behaviour.

Particular attention is devoted to data quality, protocol standardization, and the construction of structured datasets suitable for longitudinal studies. Acquired signals undergo filtering, segmentation, and normalization procedures, enabling the extraction of quantitative descriptors related to coordination, symmetry, muscle activation patterns, and motor control strategies.

Advanced machine learning and artificial intelligence techniques are then applied to identify functional patterns, classify clinical conditions, and discover digital biomarkers associated with disease progression. The objective is not only to classify movement patterns but also to gain insights into the physiological and pathological mechanisms underlying them.

Applications include monitoring patients affected by neurological and neuromuscular disorders, assessing fall risk in older adults, supporting rehabilitation programmes, and analysing athletic performance. These competencies are also being leveraged for the development of intelligent focal vibration stimulation systems, tele-rehabilitation platforms, and predictive models based on neuromuscular Digital Twins, opening new perspectives for increasingly personalized and preventive healthcare.