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How can agile sensing improve recycling stream characterisation and monitoring for e-waste? - news from the HELIOS lab

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Increasing volumes of electrical and electronic waste (e-waste) demand for innovative and efficient recycling solutions to keep materials in the process/recovery loop. The recovery percentage and quality of resulting recycling products depend fundamentally on the ability to accurately identify the constituents of the e-waste stream. Traditionally, recycling is based on sequential enrichment of target components and reduction of hazardous substances with random sampling from an assumed homogeneous mass. E-waste represents in this context a highly heterogeneous, complex waste composed of a variety of different compounds required to meet the high diversity of functional requirements. Tailored sensor-systems can achieve a successful extraction of several target materials such as precious metals or specific polymers, but reach their limits for many low concentrated, critical raw materials. Hazardous substances and additives (e.g. dark pigments in polymers, poisonous oxides) are difficult to remove from the stream and induce risks of down-cycling, quality loss and reduced acceptance of recycling products.

HELIOS lab is an agile solution for non-invasive sensing applied to complex recycling streams such as e-waste suited for conveyor belt operations. We employ hyperspectral imaging technology for the fast and spatially resolved acquisition of information associated with physical material properties. Multiple cameras allow for combining reflectance information from the visible to midwave-infrared wavelengths range to differentiate material classes. Fast data processing routines then allow for generating first order material maps. Such maps suffice for well defined, relatively homogeneous material streams but not for a precise and accurate sorting and process monitoring. For efficient e-waste recycling, further information is required to enhance the component identification, particularly for certain critical raw materials and complex compounds. We suggest additional validation cycles to refine the initial mapping. Several sensors traditionally used for bulk measurements deliver the solution for detailed point validation. Here, Raman spectroscopy, XRF and LIBS provide the needed complementary data for the identification of a wide range of critical raw materials and hazardous e-waste components. Additionally, our in-house developed laser-induced fluorescence (LiF) system contributes a scanning solution for rare-earth

element mapping. However, those validation sensors are very sensitive to signal integration times, power and focus distances. We showcase two examples for a combination of Raman spectroscopy and LiF with hyperspectral imaging technology to extract meaningful information from typical e-waste streams such as printed circuit boards and electrolysers in a conveyor belt setting. We discuss the main challenges and give an outlook on additional development needs that we will address in our HELIOS lab in the frame of the EU funded projects RAMSES and inSPECtor (EIT RawMaterials), and the BMBF funded projects High-speed imaging, InfraDatRec, Digisort and H2Giga.