New sensor based systems for economic electronic waste recycling

Dr. Axel Kulcke, DI Peter Kerschhaggl

EVK DI Kerschhaggl GmbH;

Josef Krainer Str. 35, A-8074 Raaba, Austria,

Tel. +43 (0)316 46 16 64-45, axel.kulcke@evk.biz, www.evk.biz

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1. Introduction

Due to the regulations of the European Union regarding electronic waste treatment and also the restrictions of the export of waste, the recycling of electronic waste gets a relevant topic in recycling industry.

On the opposite site the treatment of electronic waste is due to the large number of special tasks a difficult problem to solve and still manual sorting is an often used possibility to get economical valuable parts out of the material. Due to increasing material coming back from users the manual sorting can't be the technique for the future.

Different recycling technologies are still tested or running in pilot plants, but all technologies have different problems. Up to now, sensor based sorting, which is the favourite sorting technology in other recycling applications (glass, polymers, metal), is not applicable, because the restrictions of the input material (size and diversity) are as important, that conventional sensors can't do the job.

In this paper we want to introduce two new sensor systems for the sensor based sorting of electronic waste. Both systems are just introduced by recycling machinery builders in the market and give new possibilities for **an economical recycling** of different fractions of electronic waste.

Electronic waste, from the physical point of view, is a combination of different metals, polymers (hydrocarbons) and glasses. Due to the diversity of materials and the different combinations it's a difficult question how to recycle the waste on an economical and environmentally acceptable way. Because up to now there is no general answer to this question, we want to show with the new sensors 2 possibilities to solve parts of the problem. The first introduced sensor based sorting system emphasizes the metal part and printed circuit boards of the waste and the second part emphasizes the polymer fraction.

2 General tasks in sorting machinery for electronic waste

In general there are established technologies and processes for the recycling of different waste inputs. One of the oldest technologies is the recycling of bottle glass. The technology is well established and machinery is used all over the world. The recycling efficiency to the new products is in the order of 80% and today the main reason for recycling is that the recycling process is more efficient, than to produce glass from fresh material (less energy input to melt recycled glass).

In other waste fractions, there are also established processes (paper, metal, polymers), but the variations of processes used in different plants is much larger.

For the electronic waste up to now there are no fixed sorting processes established. Reasons are that the need of machinery for this task is still new and also the technical problems are still not being solved completely.

In general the problem for the machinery faces as follow:
The input fraction has a much larger diversity as other waste materials. So much more sorting steps have to be performed, before a valuable material can be generated. Also the complexity of the products to recycle is much higher than in other systems. To apply an automated sorting the products have to be shredded in much smaller fractions. These smaller fractions are more difficult to detect and also the throughput of such machinery is lower. This makes the processes more expensive and less economical. On the other side the output of sorted material in some cases is more valuable. Especially printed circuit boards with the high contend of inert metals (Au, Ag, and Pt) is an interesting sorting product. Also the copper is an important resource to recycle. The increased value of these materials makes a processing of the waste economical interesting.

3 A combination of optical and inductive metal detection for sorting electronic circuit boards and a metal fraction

Inductive and optical sorting machinery are standard sorting tools in metal recycling industry today (sorting of non ferrous metals, stainless steel and colour metals). All plants use a shredding and sieving process to select different size fractions as material pre-processing. Than ferromagnetic metals get separated with magnetic techniques and non ferrous metals get separated with eddy current separators or with inductive sensor based sorting machinery. The sensor based sorting also can divide between stainless steel and other non magnetic metals (Cu, Al, Zn, and Mg). In development status are sensors, which can selectively sort different NE-metals by inductive signals.

In the field are, due to restrictions in the machinery and the sensor technology, up to now mostly sensors used, which detect compact metal parts from sizes larger than 5mm diameter, which are mostly not relevant for electronic recycling. Due to extensive work inductive sensors from EVK got enhanced in the last 2 years (high sensitivity), that they also can detect and sort very small metal parts. The sizes for detection go below 2mm. So the sensors and the adopted machinery are now a tool for the automated recycling of electronic waste.

The shredding and sieving of electronic waste gives different fractions between 5 mm and 50mm in diameter. The main fractions are metals, polymers and glass. So the first mandatory step is to separate metals and plastics as good as possible. For this application we want to introduce the sorting machinery, which uses the combination of the optical colour information and the inductive metal information.

The material travels with about 2m/s through a detection zone. From the upper side a compact colour camera sensor (High resolution colour sensor with integrated LED light unit) detects the colour of the material and from the lower side a high sensitivity/resolution inductive sensor detects the metal content of the material. The signals are combined in a software tool, which combines the signals and also performs different object processing and weighting steps. With this technology it is possible to sort for example green printed circuit boards from green housing polymers. A typical application for this machinery is a 3 way sorting stage, where the first output are green, brown and yellow printed circuit boards and the second output are all other materials, which contain all kinds of metal (mostly Cu from cables). The third fraction typically is a mixture of polymers and glass, which can be sorted with standard glass sorting machinery.

A user can change the sorting task by different parameters, so that also other tasks can be performed with this sensor combination (selecting black or colour polymers, sorting colour metals, etc).

In table 1 the typical parameter of such sorting machinery should be given.

Table 1: Parameters of a combined colour and inductive sorting sensor “Corona”

Parameters		
Grain size	mm	approx. 5-100
Chute width	mm	typ. 1000mm (from 400-3000)
Material speed	m/s	approx. 2m/s
Resolution inductive sensor	mm	12.5
Resolution colour sensor	mm	1.5 or less
Output*	%	up to approx. 95
Sorting grade purity*	%	up to approx. 98
Throughput capacity of material	Mg/h	approx. 3.0

In figure 1 a sorted fraction of printed circuit material is shown. In this case the input fraction was in the range from 5mm to 50 mm size. In the left picture are the samples for the inductive sorting and in the right picture are fractions sorted with the Corona system. The left picture on the left side there are sample parts, which where detected with no faults at distances of 2mm and 6mm from the sensor. On the right side there are samples, which got detected with 2mm distance safely and with 6mm not correct or critical. The 2mm distance simulates a chute system and the 6mm the conveyor belt system

Figure 1: sorted fraction of printed circuit material with the Corona sensor

4. Sorting of plastics and flame retardants with high resolution 2D near infrared spectroscopy

4.1   Helios 1.7 general system description

Near infrared spectroscopy is the established technique to sort polymers from household packaging materials for recycling of PET and the PE/PP/PS fractions. A main topic for sorting in the last years is RDF (Refuse Derived Fuel) generation from industrial waste. This topic is already more difficult, because the input is more variable and the size fraction is already sometimes smaller than from packaging material.

For the sorting of polymers from electronic waste the technology of sorting has to be developed in 3 areas:

- Resolution for smaller **grain sizes**

- Better spectroscopic identification to detect **flame retardants and blends**
- Better signal to noise or spectral detection region (1.5µm-2.5µm) to sort **dark polymers** with weak spectral features.

In different publications to this topic [Sieber, 2005; Leitner, 2006] spectral imaging was proposed as basic technology for this sorting task. Due to the difficulty of this technology only medium resolutions sensors are used for paper recycling [CTR, 2006].

We want to introduce the Helios 1.7 system from EVK, which made progress in some of the development steps. This system is already running in the first applications in field. Also a second system with spectroscopy up to 2,5µm is close to field tests, which can additionally be used for the sorting of dark polymers.

The Helios sensor was introduced earlier [Kulcke, 2006; EVK, 2006]. The system is based on a 2D transmission imaging spectrometer, a commercial 2D InGaAs camera (internally modified), a FPGA based fast data processing unit and the standard EVK Hard- and Software platform for sensor based sorting of bulk material

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The parameters of the basic system are given in table 2

Table 2: Parameters of a 2D NIR spectroscopy system Helios 1.7

Parameters		
Wavelength(spectroscopy)	µm	1.1 – 1.7
Resolution (spectroscopy)	pixel	Up to 320
Resolution (spatial)	pixel	256
Timing	Lines/s	120-700
Grain size	mm	approx. 10-100
Conveyor belt width	mm	typ 1000mm (from 400-3000)
Material speed	m/s	approx. 2m/s
Output	%	up to approx. 95

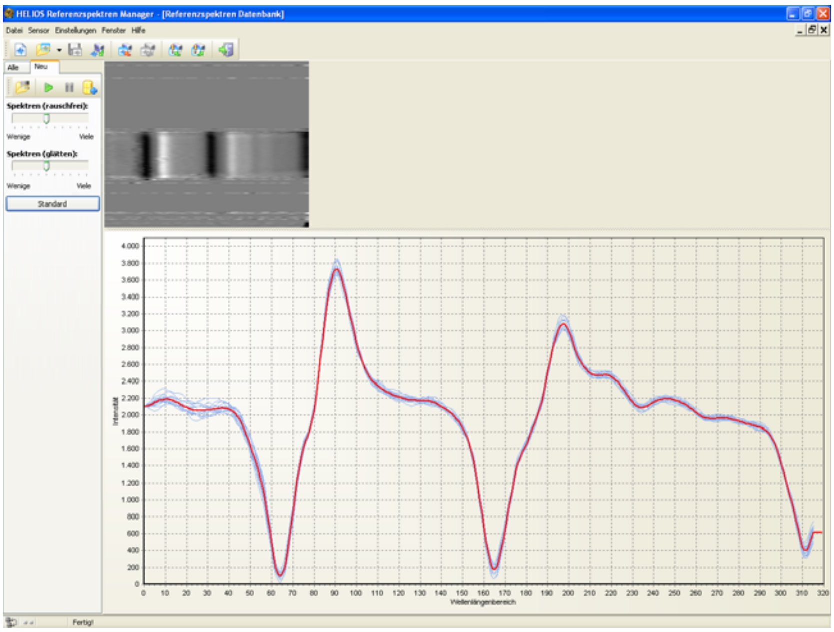

Figure 2: Typical spectra of a polymer piece on a black conveyor belt. Shown in the upper part is the online calculated spectrum (pre-processing, first derivative and intensity calibration). In the lower part is the typical spectrum displayed in combination with the spectra from different spatial points on the probe.

The Helios system can identify up to 8 trained spectral classes simultaneously and can be parameterized for different sorting task by the end user in the recycling plant. The actual system runs with 120 Hz line rate at full spectral resolution. The system also can run at higher line rates with reduced spectral or spatial resolution, which can be helpful for special tasks, especially for electronic waste.

For typical sorting tasks in electronic waste recycling the Helios 1.7 device can be a help to generate valuable products from the polymer fraction of the waste and reduce the unused fraction of the input material. A problem which still is not solved with this device is the sorting of black polymer fractions.

Due to the needs of recycling machinery builders EVK is developing 2 new devices based on the Helios 1.7:

- A system with higher resolution and more flexibility based on an own InGaAs (up to 1.7 µm) camera.
- A system based on an HgCdTe sensor (up to 2.5 µm).

The advantages of the 2 new systems should be described shortly. The expanded 1.7 µm system is based on 4 times increased basic pixel rate. Also the whole parameterisation of the sensor is included in the EVK software, that there is even more flexibility for the adjustment of the application and sorting tasks. In the processing data chain also additional features like the second derivative and typical spectroscopy tasks (PCA) are planned to get implemented.

The 2.5 µm system should be mainly used for special sorting tasks. The system takes the spectral information from the region 1.5 to 2.5µm. In this spectral region the spectral absorption of polymers is stronger due to quantum mechanical basics in chemistry. This gives more flexibility to detect smaller fractions in the spectra (flame retardants and composites) and also the classification of dark polymers can be enhanced. In table 3 a comparison of different systems for different sorting tasks is given.

Table 3: sorting tasks in polymer recycling with qualitatively stating of the use of the sensor system

Sorting task	**Helios 1,7 µm**	**Helios 2,5 µm**
PET,PP,PE, PS,PVC from packaging material	++	++
RDF sorting from industrial waste	+	++
Polymers from electronic waste	+	++
Flame Retardants in polymers from electronic waste	**0**	++
Polymers in automobile recycling (dark polymers)	-	+
PET Flakes or fine grain	++	-

4.2 Sorting of flame retardants and polymer compositions with Helios 1.7

For electronic waste recycling a special problem has to be faced. The polymers are quite often mixed with flame retardants or different polymers are mixed to a polymer blend. These flame retardants are normally based on polymers modified with halogens. Most of them use bromine or fluorine. These modified chemicals have to be detected separate and have to be treated. One of these chemicals is TBBPA. The chemical substitution is also detectable in the spectrum. One example is shown in figure 3.

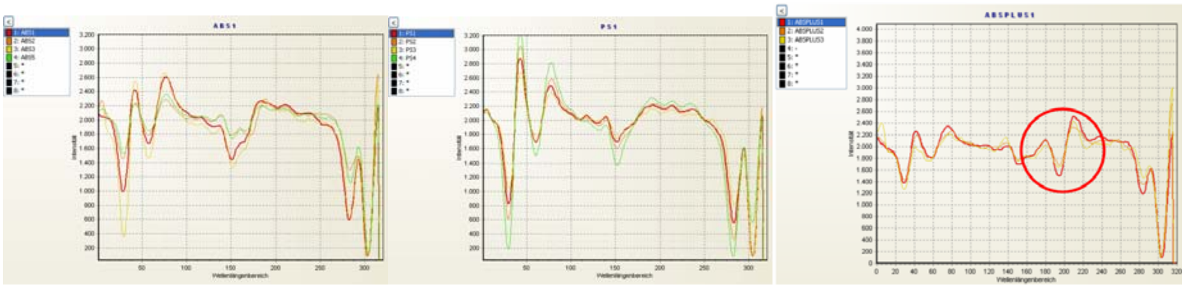

Figure 3: Spectra of different samples of ABS, PS and ABS composed with TBBPA (first derivative, normalized)

Normally the flame retardants are detectable with the spectroscopic system. For some chemicals the Helios 2.5 system is needed, because the spectral features are at wavelength between 1.7µm and 2.5µm.

For housings of electronic devices the producers mostly also use polymer blends. These blends can be identified with the Helios system. Due to the large number of variations this topic has to be faced by the recycling industry. Typical sorting systems only can sort 3 fractions. By this, first the sorting application has to be defined very precisely and than the spectroscopic system has to be parameterized, to exactly perform an economical and ecological sorting task.

4. Conclusion

Based on the two introduced systems and other systems based on X-ray, optical and inductive sorting there are sensors available to establish automated sorting in the electronic waste recycling industry. Due to the high costs of the sensor based sorting machinery there is a need to introduce economic standards, that recycling companies can plan investments in this machinery to start an economical and ecological recycling of electronic waste.

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