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An Image Analysis System for Selective Recovery of Non-ferrous Metal

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***Abstract*— To increase the recycling rate for non-ferrous metal, a high speed sorting line with a high throughput rate of up to 1ton per hour was built. The system comprises an Image Analysis System to detect shredder particles and calculate their position on the belt as well as several 2D and 3D shape features. ElectroMagnetic Tensor Spectroscopy (EMTS) or Laser-Induced Breakdown Spectroscopy (LIBS) characterize each particle based on its metal components. Tests were conducted under hard conditions in an industrial environment. For a full covered 400mm x 100mm belt area the Image Analysis System needs less than 24.5ms at a feature calculation accuracy up to 95%. The developed system can easily be adapted to other scenarios.**

I. INTRODUCTION

The requirements of the sorting line described in this work are to detect and classify non-ferrous metal particles. The load speed of the sorting line is given by 1ton/hour. A vibrating feeding system is used to load the belt (width of 400mm) and for fragment separation. Due to the limitation of the vibrating feeding system, about 28g/s of particles can be loaded with a belt speed of 2m/s. The subsystems need an accuracy of 0.5mm/px in length and width. Therefore, a line rate of 4kHz is required. Fig. 1 shows a schematic of the components and Fig. 2 a sample image of such a particle. The system is developed to work even under heavy industrial conditions (like dust, vibrations of machines, etc.).

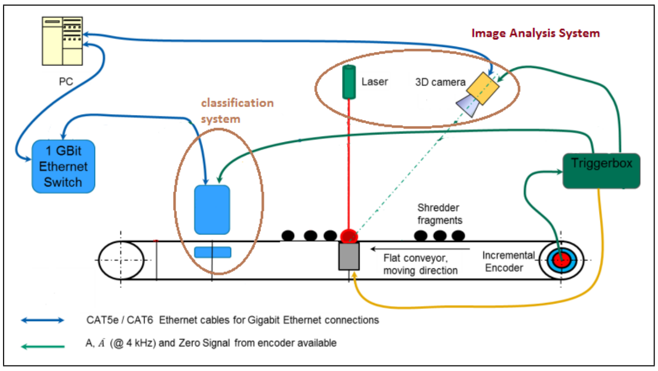

Fig. 1. Schematic of the developed sorting line.

The developed sorting line consists of two independent subsystems (detector and classifier). An Image Analysis System identifies every single particle on the conveyor and calculates its exact position on the belt as well as 2D and 3D shape features. The analysis and classification of the material of the particles is provided by EMTS or LIBS. The EMTS measures the electrical conductivity while the LIBS characterizes the chemical composition. To achieve optimum results of the classification systems, it is essential that the position and specified shape features of every single particle is derived to utmost precision by the Image Analysis System. Therefore, all subsystems are synchronised by an incremental encoder.

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II. DISCRIPTION OF SUB SYSTEMS

A. *Image Analysis System for position and shape calculation*

The Image Analysis System is based on laser triangulation and comprises a line laser, an Automation Technology C4-1280-GigE 3D camera and a computer for calculation. Using subpixel algorithms a height resolution, defined by the optical resolution and the angle between laser plane and camera, of 0.15mm can be achieved. Due to the belt movement the laser line migrates along the surface of the fragments. The camera acquires a 2D image of each laser line and calculates a 3D profile that is sent to the computer via GigE. The analysis algorithm stores the 3D profile and builds an image, called subframe (currently consisting of 200 3D profiles), a small part is illustrated in Fig. 3. The camera can acquire a grayscale image (Fig. 2) as well, but it is not used in the current application.

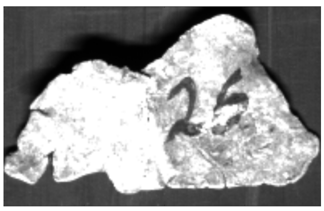

Fig. 2. Grey-value image of one metal particle

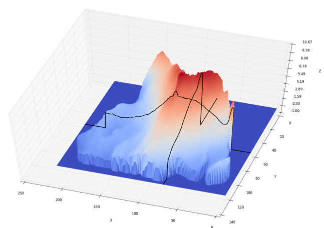

Fig. 3. 3D image of one metal particle (same as Fig. 2)

To remove noise due to non-flatness of the conveyor a background model is calculated and subtracted from the image (for each 3D profile). By binarizing the subframe with an experimentally determined height threshold areas of interest are selected. If the size of an area is big enough, it defines a particle hypothesis and features are calculated. Features reach from simple positions to more complex ones, like feret diameters or maximum cross-sectional area (overall 25 different features in 2D and 3D respectively).

B. Classification systems

The current application employs two different classification subsystems. Both systems provide a satisfactory solution for the non-ferrous metal classification. Currently linear classifiers with several features are used, but in the future neuronal networks will be trained.

The LIBS system measures the chemical composition of the particles and separates them into cast and wrought aluminium categories and into selected aluminium and magnesium alloys.[1]

The EMTS system on the other hand measures the electrical conductivity of the particles to separate the fragments into aluminium, copper and brass categories.[2]

III. RESULTS

A. Timing Performance

Due to the described settings, the maximum computation time is 50ms for one subframe. Two types of evaluations were realized with separated aluminium particles on a 1000mm x 400mm belt area. The first test (small covering, SC) simulated the real coverage with 139g particles. In the second test the belt was fully covered (full covering, FC). Three test sets of particles were used. The particles were placed on the belt and processed three times in the same arrangement. The arrangement itself was varied three times, such that nine timing tests for every particle size were done. Table I shows the test conditions and the calculation time for one subframe. As can be seen, the maximum computation time is 24.5ms for a full covered belt with 55 large samples.

TABLE I
MAXIMUM COMPUTATION TIME FOR FEATURE CALCULATION ON ONE SUBFRAME (200 3D PROFILES)

Test set	Small		Medium		Large	
Sample size [mm]	9x9		20x20		30x30	
Test size	SC	FC	SC	FC	SC	FC
Sample count	71	355	29	145	11	55
Max. time [ms]	20.91	23.33	21.26	24.1	11.78	**24.5**

B. Accuracy

To verify the accuracy of the Image Analysis System objects with defined dimensions were used (e.g. eurocents and washers) as well as real particles. Due to the complex real particle shapes no ground truth for heights, areas and diameters were available. Therefore, just the positions and recognition rates of real particles were tested.

The feature calculation accuracy is higher than 95% and almost every single particle can be detected (see Table II).

Nearly all coins were detected correctly. Only one misdetection was observed since two 2 eurocents were not separated on the belt. The small deviation of the area can be explained by the fact that reflections on the edge lead to overestimate the real object size. Thus, the height is measured also on edge regions with height values produced by reflections. The height is furthermore influenced by the shape of the coins. Only the edge has full height, whereas the rest of the surface

TABLE II
ACCURACY OF THE IMAGE ANALYSIS SYSTEM IN %

Sample	Height	Area	Diameter	Found
1 eurocent	96.74	98.13	99.89	100
2 eurocent	98.91	96.68	99.87	99
5 eurocent	99.14	99.29	99.29	100
10 eurocent	98.25	99.10	99.10	100
20 eurocent	99.67	98.33	99.27	100
50 eurocent	98.97	98.97	99.58	100
Washer 16	98.94	95.18	97.12	100
Washer 20	95.38	98.50	98.84	100
Washer 22.5	97.38	98.49	95.66	100
Shredder	-	-	-	100

is below this level caused by different motives. As can be seen in Fig. 4 the height and area could be used to derived a simple image based classifier for coins.

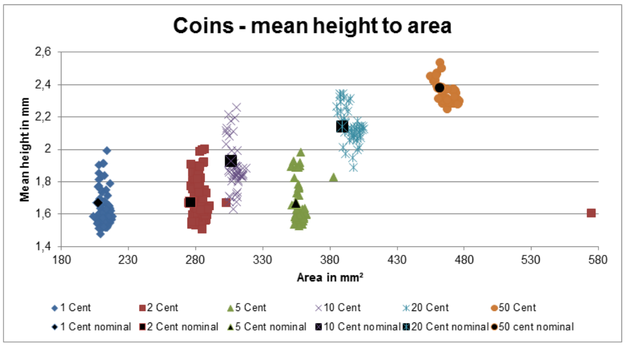

Fig. 4. Simple coin classification and comparison of the calculated values for the mean height and area with the nominal values.

All washers were detected correctly. The accuracy of the washer analysis is similar to the coins, only the area is a little less accurate, due to the hole in the middle of the washers.

The real particles were all detected by the system and the position on the belt were calculated correctly.

IV. CONCLUSIONS

In this work we have shown that the Image Analysis System is capable of detecting particles and calculating all required features at very high accuracy over 95%. This can be done in less than 24.5ms at a full covered belt with subframes of 400mm width and 100mm length. The system exceeds all requirements and has enough processing capabilities for several extensions. Its simplicity and independency of other systems enable its usage for other applications as well.

ACKNOWLEDGMENT

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