

RECOGNITION OF ELECTRONIC SCRAP FOR RECYCLING

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Abstract: This paper presents the design and performance of a recognition system for the identification of electronic components on scrap PCB's. The system comprises four measurement units: three optical imagers (yielding a range image, a high resolution grey-tone image and a color image, respectively), and an eddy current sensor (sensitive to electric and magnetic material properties). The system identifies batteries, electrolytic capacitors and integrated circuits. Its error rate is further reduced by fusion of the sensor outputs using strict Bayesian information integration.

Keywords: Object recognition, computer vision, eddy current sensing, sensor fusion, recycling.

1 INTRODUCTION

Recycling of waste materials contributes to reduction of environmental problems. A prerequisite for recycling is the separation of the primary waste streams into more homogeneous material flows. In this paper we discuss the recycling of printed circuit boards (PCB's) from outdated electronic equipment (TV sets, computers). A PCB might contain components that could be reused (memory chips) or that are harmful for the environment (batteries, elco's). We describe here a prototype measurement system developed for the identification of such components on waste PCB's. The output of the system can be used to control a desoldering robot that removes the recyclable and harmful components from the PCB. In order to increase the flexibility of the system, it is designed as a modular multisensor system.

2 THE SYSTEM SET-UP

The system consists of four identification units: a range imager based on structured light, a high-resolution grey-tone camera, a colour camera and an eddy current sensor [1]. The PCB under test passes subsequently these units. Each identification unit comes up with a hypothesis about certain components on the PCB, restricted in the prototype system to IC's (of various types), electrolytic capacitors, batteries and a rest class (all other components). These four units are described in more detail in the next subsections.

2.1 The range imager

The range imager identifies the components on the basis of 3D shape [2]. Range data are obtained using the principle of structured light, combined with triangulation. Figure 1 illustrates the structured-light principle. A light pattern, here consisting of a line grid, is projected on the scene, under a fixed angle of about $\pi/4$ rad. The scene is viewed by a black-and-white camera, with main axis perpendicular to the ground plate (reference plane). A horizontal surface of an object shows projected lines that have been shifted with respect to those on the ground plate, to an extent that corresponds to the relative height of that surface. A slanted object surface changes the angle of the lines as viewed by the camera. Hence, by analyzing the position and orientation of the projected lines, height information can be obtained. The height calculation is based on triangulation, using known viewing and projection angles and the positions of the light source and camera.

The projection of a series of gratings, each with a different pitch, allows the reconstruction of a complete height map of the scene. In our prototype we use 8 series with binary related pitch, yielding a spatial resolution of 8 bits. To eliminate shadows (see figure 1) a second series of images is taken, with the gratings being projected from a different angle. Figure 1 only shows three of these 16 images. In Fig. 2, a range image is shown, where the height is converted to brightness. In this representation of the height map, the objects can be clearly recognized by a human observer.

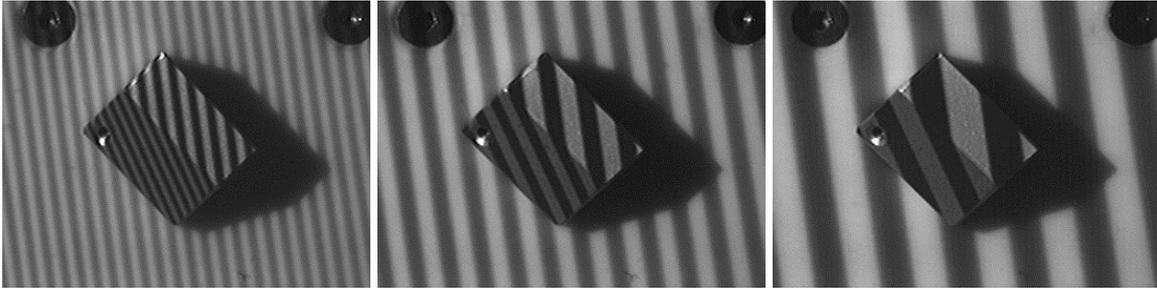


Figure 1. Principle of the structured light method to obtain 3D information from a 2D image. Three images out of a sequence of eight are shown. Shadows are eliminated by a second series of images, through projection of the lines from a different angle.

The next step in this recognition unit is to extract 3D features from the height map, and to fit them to model features of the objects to be classified. In this project, the objects are modelled by superquadrics:

$$f(x, y, z) = \left\{ \left(\frac{x}{a_1} \right)^{\frac{2}{\epsilon_2}} + \left(\frac{y}{a_2} \right)^{\frac{2}{\epsilon_2}} \right\}^{\frac{\epsilon_2}{\epsilon_1}} + \left(\frac{z}{a_3} \right)^{\frac{2}{\epsilon_1}} = 1$$

The shape and size of the components can thus be characterized by a set of five parameters: a_1 through a_3 describe the size (length, width, thickness) of the object, whereas ϵ_1 and ϵ_2 model the shape (roundness). Of all components to be recognized, this set of parameters is experimentally determined from their actual shape and size, and is stored in the data base. Recognition is accomplished by comparing the measured set of parameters with those in the data base.

Now, from the height map, possible components are first isolated (a process governed by the knowledge about minimum and maximum object dimensions). Next, a superquadric is fitted to each cluster of range data points, yielding the five parameter values. These values are compared to the sets in the database; according to a minimum distance criterion, and a hypothesis is generated for each of the components on the PCB. The minimum distance is taken as a measure for the uncertainty of the hypothesis.

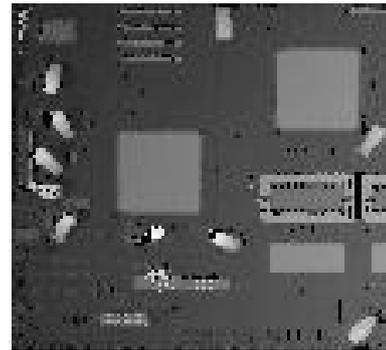


Figure 2: Range image; height is converted to brightness

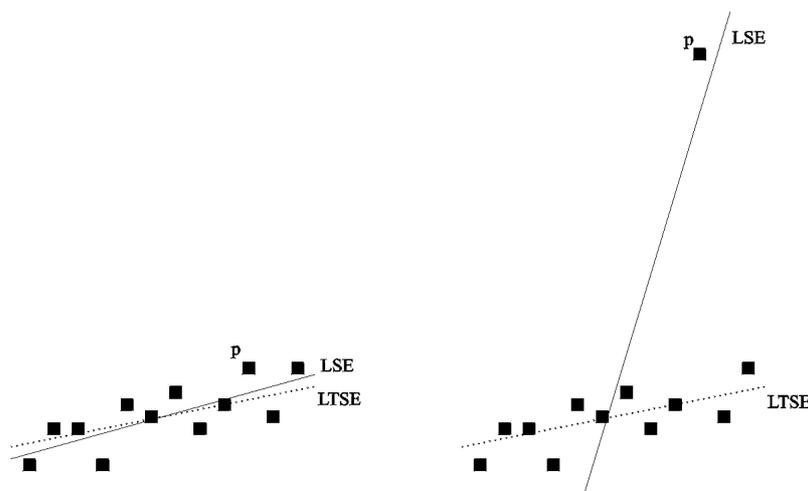


Figure 3. Two examples of fitting a straight line to a data set. The two sets are equal except for point p, which has different positions.

During the realization of the system, several problems showed up. One of these is the lack of data points from the back side of the object. We completed the data set by adding points corresponding to

the (known) base plate. In this way ambiguity in the fitting results was strongly reduced. Another problem is related to outliers: data points that have high probability not to belong to the object. The algorithm to reduce the effect of such outliers is illustrated in figure 3, which shows two examples of fitting a straight line to a data set. The sets are equal except for one point p . Two fitting algorithms are compared: the LSE (least squares estimate) and the LTSE (least trimmed square estimate) [5]. In the latter algorithm a number of points that are relatively far from the center of gravity are excluded from the set of range points. This significantly reduces the effect of outliers as the point p . Although no knowledge is available about the points being outliers or not, experiments showed that the fitting results are much more reliable using the LTSE algorithm. So, an estimate should rely on the majority of data points rather than on a complete set.

2.2 High-resolution image

Characteristic details in a high-resolution image are checked in the second station. For instance, the presence of an array of small bright points indicates an IC (figure 4). Such arrays are detected using template matching techniques. The system counts the number of horizontally and vertically positioned pins, and compares this information with corresponding data in the data base. For instance, a hypothesis could be generated indicating a dual-in-line IC with 2 rows of 8 pins. Particular types of integrated circuits are recognized in this way.

Although in principle the resolution is sufficient for optical character reading (figure 4) this option is not used in the prototype.

2.3 Color image

The colour camera system uses the spectral characteristics in the image of the PCB, to obtain a proper segmentation of the regions representing the objects of interest [3]. This segmentation process is further improved by using a priori knowledge about the component's shape, whereas the object recognition is performed using the technique of inexact attributed graph matching [4].

A color image is an excellent modality for model based object recognition. The sequence of steps in the recognition process is as follows: image acquisition, normalization and filtering; segmentation, transformation into an attributed graph, and finally inexact matching resulting in a hypothesis about the object's identity. In this module, the components are modelled by attribute graphs, that are sets of primitives with attributes (regions with a certain color and shape) and relations between these primitives (adjacent, enclosed). For example, an IC is modeled as a black rectangle with adjacent an array of small bright parts (the pins). An example of a recognition result from the color imaging unit is given in figure 5.



Figure 4. Detailed image of an IC, obtained with the high-resolution line-scan camera.

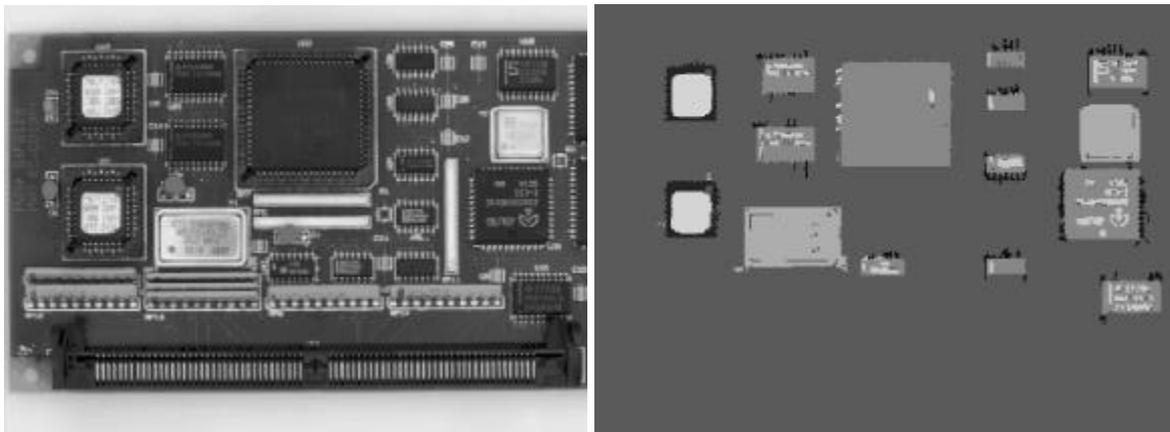


Figure 5. left: image of a PCB; right: the recognized components from the left (color) image, using attribute graph matching. Obviously, all connectors have been rejected by the system. One of the small IC's has been falsely overlooked.

The method is only feasible when proper color images are obtained. Practical difficulties with this respect have been solved in the prototype by the application of circular diffuse illumination and the use of an achromatic doublet (lens) to reduce chromatic aberration.

Further, changes of the object color due to remaining highlights and shadows are dealt with by advanced segmentation algorithms. The method allows identification of oddly shaped objects too, for instance an empty IC-socket, see figure 5.

2.4 Eddy-current sensing

The eddy-current sensor is used here as an additional test for those components that are identified with insufficient certainty. Since the coordinates of these components are known from the previous units, this test requires only a single measurement point, which speeds up the process significantly.

The eddy current sensor consists basically of a coil, whose impedance changes when a conductive or ferromagnetic material approaches the sensor. Roughly, the selfinductance decreases with conductivity of the material (due to induced eddy currents), and increases with magnetic permeability (due to reluctance changes). Normally, the eddy current sensor is used as proximity sensor, as the impedance varies strongly with distance to the object. In this project, the distance to the object is made zero, by moving the sensor head towards the object (component) until touch. Both the real and imaginary part of the sensor impedance is measured, over a frequency range from 0.5 to 2 MHz. The components are characterized by the resonance frequency and the impedance value at that frequency. These parameters are characteristic for the component material (at the surface of the component). As an example, figure 6 shows the real part of the impedance for three different materials; the curve for the situation when no object is present is included as a reference.

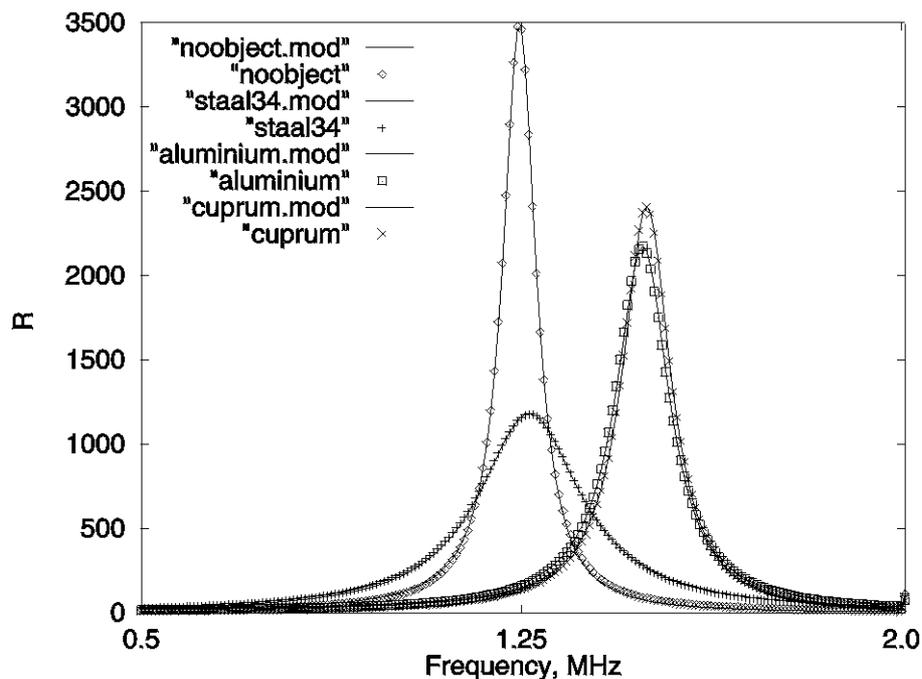


Figure 6. Real part of eddy current sensor impedance, showing characteristic resonance frequency and impedance level, for various materials: steel34, aluminium and copper. Note that copper and aluminium are not well distinguishable in this set-up.

Objects are classified on the basis of two parameters: the resonance frequency and the value of the real part of the impedance at resonance frequency. These values are determined a priori for all components that should be recognized. This information is stored in a data base. The measured values for unknown components are compared to the reference data, similar to other recognition schemes.

3 SENSOR FUSION

Each of the first three stations generates a set of hypotheses about the possible identity of the components on the PCB, and to each of these hypotheses a measure for the likelihood is connected. The three likelihoods are combined to a total likelihood, according to probability theory. This is not a trivial process, because the uncertainty is different for the various identification systems; not all objects are identified by all systems; and conflicting hypotheses may occur. For instance, the range imager can hardly distinguish between empty and occupied IC-sockets and the colour camera has some difficulties in detecting electrolytic capacitors. In this application the hypotheses from the first three stations are combined using strict Bayesian integration method for data fusion [5].

4 RESULTS AND CONCLUSIONS

The performance of the system has been evaluated by testing a large number of different PCB's with known components. For a particular set of PCB's, the observed recognition rates for the individual sensors are: range module 71%, high-resolution module 74% and color module 61%. Sensor fusion increased the recognition rate to 82%. In particular elco's had a low rate: 53% only. Obviously, extension with the eddy current sensor could substantially improve the recognition rate.

Finally, figure 6 shows the prototype recognition system. The front plate has been removed to allow viewing the inside. During operation, the case has to be closed, to exclude spurious light from the environment. Even inside the main case, the color imaging unit and the line scan unit have got their own protective case to ensure proper illumination.

The projection of the line pattern is accomplished with only one series of gratings; the different projection angles are obtained using moving mirrors (see B in figure 6).

The recognition time is not optimized to a minimum, in this phase of the research. The various recognition algorithms run on different computers. However, the total recognition time for one PCB when optimized for speed can be in the order of several minutes, including the transport time between the various units.

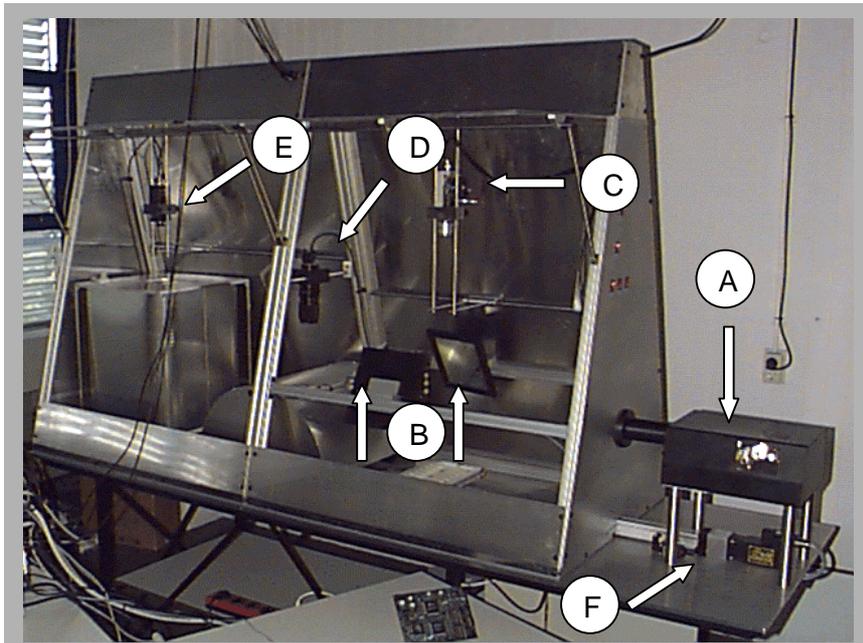


Figure 6. View on the interior of the prototype recognition system. A: projector for structured light; B: movable mirrors; C: camera viewing the structured light scene; D: high resolution line scan camera; E: color camera; F: drive for transport system

It is shown that the concept of multi-sensor object recognition is feasible for the case of electronic components on a PCB. The hypotheses from the individual measurement units can be combined to increase the success rate of the recognition process. Most algorithms that are applied in this case study have a more general applicability, so they can be used for other types of objects as well. Moreover, the modular set-up of the system allows flexible adaptation to other classification problems,

for instance for the separation of particles in bulk streams of waste materials. Further research is directed towards this type of applications.

5 REFERENCES

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