A GEOMETRIC APPROACH TO CLASSIFICATION OF TRASH IN GINNED COTTON

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Abstract. *This paper discusses the use of geometric approach to classify different types of trash (non-lint, non-fiber material) in ginned cotton. Pieces of trash can have complicated shapes, so we would like to find a good approximating family of sets. Which approximating family is the best? We reduce the corresponding optimization problem to a geometric one: namely, we show that, under some reasonable conditions, an optimal family must be shift-, rotation- and scale-invariant. We then use this geometric reduction to conclude that the best approximating low-dimensional families consist of sets with linear or circular boundaries.*

This result is in good agreement with the existing empirical classification of trash into bark1, bark2, leaf, and pepper trash.

A practical problem: brief description. The main use of cotton is in textile industry; for that purpose, we only need cotton fiber called *lint*. Mechanical harvesters collect fiber together with the seeds. To separate lint from the seeds and from other non-lint material, a special process called *ginning* is used. Ginned cotton consists primarily of lint, but some non-lint material (*trash*) is left. For the further textile processing, it is important to know how much trash of what type is left.

In principle, it is possible to detect the amount and type of trash by visual inspection, because trash is usually of different color than the whitish lint and is thus clearly visible. The problem with visual inspection is that the visual inspection of all 15 to 19 million bales of cotton annually produced in the USA is a very time-consuming and expensive process. It is therefore desirable to develop an automatic system for the analysis of trash in ginned cotton (see, e.g., [Lieberman et al. 1994], [Lieberman et al. 1997]).

Since trash is clearly visible on the lint background, it is natural to take a photo of a cotton bale, and then run a computer program to analyze this photo. Our goal is to separate trash from lint; since trash is of different color than the lint, we can ignore the details about the intensities of different pixels and use a threshold on intensity to transform the original image into a black-and-white one: points in which the intensity is above the threshold are treated as white (i.e., as lint), and points in which the intensity is below the threshold are treated as black (i.e., as trash).

As a result, we get a black-and-white picture in which several pieces of trash are present on the white background. Pieces of trash can have complicated shapes. The user needs a simple classification of these shapes. A natural way of classifying different shapes is to describe several simple approximate shapes, and then to classify a given piece of trash based on which simple shape it resembles most. So, to develop a good classification of trash in cotton, we need to find a good approximating family of sets.

Because of the large volume of cotton processing, even a small gain in classification quality can lead to a large economic benefit. It is therefore desirable to look not simply for a *good* approximating family of sets, but rather for a family which is *optimal* in some reasonable sense.

Of course, the more parameters we allow, the better the approximation. So, the question can be reformulated as follows: for a given number of parameters (i.e., for a given dimension of approximating family), which is the best family? In this paper, we use a geometric formalism developed in [Kreinovich et al. 1999] and [Wolff et al. 1999] to formalize and solve this problem.

Formalizing the problem. In this formalization, we will, in effect, follow [Kreinovich et al. 1999] and [Wolff et al. 1999].

The pieces of trash are usually smooth lines or areas with smooth boundaries, so it is reasonable to restrict ourselves to families of sets with analytical boundaries. By definition, when we say that a piece of a boundary is analytical, we mean that it can be described by an equation $F(x,y)=0$ for some analytical function

$$F(x,y)=a+b\cdot x+c\cdot y+d\cdot x^2+e\cdot x\cdot y+f\cdot y^2+\ldots$$

So, in order to describe a family, we must describe the corresponding class of analytical functions $F(x,y)$.

Since we are interested in families of sets which are characterized by finitely many parameters (i.e., in finite-dimensional families of sets), it is natural to consider finite-dimensional families of functions, i.e., families of the type

$$\{C_1\cdot F_1(x,y)+\ldots+C_d\cdot F_d(x,y)\},$$

where $F_i(z)$ are given analytical functions, and $C_1,\ldots,C_d$ are arbitrary (real) constants. So, the question becomes: which of such families is the best?

When we say "the best", we mean that on the set of all such families, there must be a relation $\geq$ describing which family is better or equal in quality. This relation must be transitive (if A is better than B, and B is better than C, then A is better than C).

This relation is not necessarily asymmetric, because we can have two approximating families of the same quality. However, we would like to require that this relation be *final* in the sense that it should define a unique *best* family $A_{\rm opt}$ (i.e., the unique family for which $\forall B\,(A_{\rm opt}\geq B)$. Indeed:

- If none of the families is the best, then this criterion is of no use, so there should be *at least one* optimal family.

- If *several* different families are equally best, then we can use this ambiguity to optimize something else: e.g., if we have two families with the same approximating quality, then we choose the one which is easier to compute. As a result, the original criterion was not final: we get a new criterion ($A\geq_{\rm new} B$ if either A gives a better approximation, or if $A\sim_{\rm old} B$ and A is easier to compute), for which the class of optimal families is narrower. We can repeat this procedure until we get a final criterion for which there is only one optimal family.

The exact shape depends on the choice of a starting point, on the orientation of the camera, and on the choice of the zoom. It is reasonable to require that if we change the starting point, the orientation, or the zoom, the relative quality of different approximating families should not change. In other words, it is reasonable to require that the relation $A\geq B$ should not change if shift, rotate, or scale the image; i.e., the relation $A \geq B$ should be shift-, rotation- and scale-invariant.

These requirements can be formalized as follows:

Definition 1. *Let $d > 0$ be an integer. By a d-dimensional family, we mean a family A of all functions of the type*

$$\{C_1 \cdot F_1(x, y) + \ldots + C_d \cdot F_d(x, y)\},$$

where $F_i(z)$ are given analytical functions, and $C_1, \ldots, C_d$ are arbitrary (real) constants. We say that a set is defined by this family A if its border is described by an equation $F(x, y) = 0$, with $F \in A$.

Definition 2.

- *By an optimality criterion, we mean a transitive relation $\geq$ on the set of all d-dimensional families.*
- *We say that a criterion is final if there exists one and only one optimal family, i.e., a family $A_{\rm opt}$ for which $\forall B\, (A_{\rm opt} \geq B)$.*
- *We say that a criterion $\geq$ is shift- (corr., rotation- and scale-invariant) if for every two families A and B, $A \geq B$ implies $TA \geq TB$, where TA is a shift (rotation, scaling) of the family A.*

Proposition. ([Kreinovich et al. 1999], [Wolff et al. 1999] *Let $d \leq 4$, let $\geq$ be a final optimality criterion which is shift-, rotation- and scale-invariant, and let $A_{\rm opt}$ be the corresponding optimal family. Then, the border of every set defined by this family $A_{\rm opt}$ is either a straight line interval, a circle, or a circular arc.*

Discussion. The only shape which actually bounds a 2-D set is a circle which bounds a disk. So, as a result of this proposition, we have the following trash shapes:

- straight line intervals,
- circular arcs, and
- disks.

When the disk is small, we can view it as a point, which leads us to the fourth possible approximate shape of cotton trash:

- points.

This classification is in perfect agreement with the existing empirical classification of trash into:

- *bark1* (approximately circular arcs),
- *bark2* (straight line segments),
- *leaf* (disks), and
- *pepper trash* (points).

The names of these types of trash come from their physical meaning, with the only exception of *pepper trash* which refers to broken or crushed pieces of leaf.

Practical application. We have used this geometric classification to develop a prototype system for classifying trash. In our system, images (640×480) are acquired using a 3-chip CCD Sony color camera. The imaging hardware consists of a Matrox IM-1280 imaging board and CLD acquisition board. The pixel resolution is 0.13 mm (0.005 inches).

The acquired images are flat field corrected for spatial illumination non-uniformity. Each acquired color image (RBG) is converted into hue, luma (intensity), and saturation (HLS) color space (see, e.g., [Russ 1994]), and a threshold on intensity is used to create a black-and-white image.

The system uses intelligent pattern recognition techniques (see [Siddaiah et al. 1999], [Siddaiah et al. 1999a]) to detect different shapes.

Practical results. The resulting systems achieves a 98% correct classification of trash – a much higher percentage than the previously known methods.

Open problem. We described optimal 4-D approximating families. These families give a rather crude description of the actual trash shapes. To get a better understanding of the trash, we may need better approximation, so we may need to use more parameters in the approximating family of sets. Here comes an open problem: we know the optimal 4-dimensional families, but we still need to find out the optimal 5-, 6-, etc.- dimensional families for locating trash in ginned cotton.

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