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A PRACTICAL PACKING STRATEGY FOR THE AUTOMATED HANDLING OF IRREGULAR SHAPES

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This paper has two distinguishable, but interwoven themes: (i) maximising the use of the context information available from a given task, by the application of a systems engineering approach to the packing problem, and (ii) the development of an adaptive packing strategy for random shapes, using morphological and heuristic techniques. The packing techniques and applications discussed in previous papers[1-3] provide an important motivation to the development of automated packing systems. They also indicate the best means of progressing the development of flexible packing systems. The characteristics required in a flexible packing system are summarised below:

- Adaptive and easily tuned to specific applications.
- Ability to manipulate all shapes efficiently.
- Shape ordering and orientation capabilities.
- Visual feedback to aid operation.
- Ability to account for systems issues, such as changes in the product, process and the industrial environment.
- Quantitative validation procedure.
- Easy to use, interactive environment to facilitate experimentation.
- Limited propagation of errors (especially important for large packing / assembly tasks)[4] .
- High speed operation.
- Facility to implement non-local packing strategies.

Essentially, such a system will consist of two main components. The first will provide a means of manipulating the shape and scene image at a geometric level. The second component will consist of a rule based geometric reasoning unit capable of deciding the ordering and orientation of the shapes to be packed. The heuristic component must also be capable of dealing with the system issues arising from a specific application demand. This task can be simplified by maximising the use of the information available from the product, process and the environment for a specific industrial application. By using heuristic methods it is hoped that the packing systems generality is improved and that the development of procedures for new applications will become less cumbersome. One of the key features in such a system is that it should work towards an efficient solution, accepting that we cannot guarantee reaching an optimal solution. Therefore a mechanism for quantifying the packing systems performance will be necessary. This will enable a quantitative comparison of packing procedures. Burdea and Wolfson[4] suggest that the integration of such a heuristic approach with a packing verification procedure should ensure convergence to an efficient solution.

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The packing scheme consists of two major components (see Fig 1):

(a) A *geometric packer*, based on the principles of mathematical morphology, takes an arbitrary shape in a given orientation and puts the shape into place *in that orientation*[1,2].

(b) A *heuristic packer* which is concerned with the ordering and alignment of shapes prior to their application to the *geometric packer*. This component also deals with other general considerations, such as the conflict in problem constraints and the measurement of packing performance. In addition, it deals with practical constraints, such as the effects of the robot gripper on the packing strategy, packing in the presence of defective regions, and pattern matching considerations[3]. A more detailed discussion of the system implementation can be found in Whelan and Batchelor[1,2].

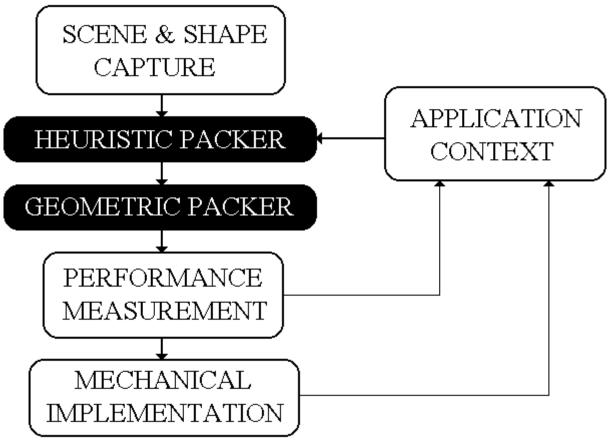

Fig. 1. General industrial packing strategy.

Together, these form a flexible strategy that allows the packing of arbitrary, two-dimensional shapes in a previously undefined scene, see Fig 2. The aim of the design was to produce a flexible system capable of dealing with the majority of industrial packing problems, and as such, the system was not designed around a specific application. As Burdea and Wolfson[4] point out, no single strategy, however efficient, will succeed in dealing with all shapes equally well. Therefore, when faced with a specific application, the system can be tuned to that task.

Performance Measures

To ensure that we have confidence in the global efficiency of any packing strategy, there must be some way of measuring its performance. Traditionally, packing performance has been measured by a single number, called the *packing density*[5]. This is the ratio of the total area of all the packed shapes to that of the total area of the scene. This is referred to as the *worst case analysis* packing measure.

A number of other performance measures have been developed in the field of operational research, particularly for comparing different heuristics for packing rectangular bins by odd-sized boxes[6]. These performance metrics fall into two main categories: *Probabilistic* and *statistical* analysis. While these performance measurements can be quite useful in well constrained packing problems, they are of little use in dealing with the packing of arbitrary shapes. Since it is unlikely that real data will fall neatly into a uniform, or any other easily analysable distribution.

The performance measures used in this strategy are based on the traditional *worst case analysis*. After a packing procedure has been applied to a given scene, the result is assessed by a number of performance parameters[2].

- *Packing density* is the ratio of the total area of all the shapes packed, to the area of their (collective) convex hull after packing (minus the area of the scene defects). This measure has a maximum value of 1.

- The *performance index* is a modified version of the packing density. A weighting factor is applied. This is referred to as the *count ratio* and is defined as the ratio of the total number of shapes packed, to the number of shapes initially presented to the scene. The *performance index* is equal to the product of the *packing density* and the *count ratio*. The *performance index* also has a maximum value of 1. This measure accounts for any shapes that remain unpacked when the procedure terminates.

Systems Issues

In general, the design of the packing system can be greatly simplified, the more application constraints that can be incorporated into the heuristic packer. The design of packing systems for certain industries, such as shoe manufacturing, is made easier by the fact that leather, like fabric, wood, marble and many other natural materials has a pronounced grain. For example, in certain applications only two orientations of a given shoe component may be permissible, a fact which can greatly enhance the speed of the packing procedure. Again, the heuristic packer can easily take this type of application constraint into account. Alternatively, some practical considerations can increase the complexity of the packing procedure. This section will examine two such considerations, see Fig 2.

A. The effect of utilising different robotic end-effectors in automated packing.

A general purpose packing strategy must be robust enough to cope with a range of different material handling systems. For the applications considered in Fig 1(a) and (b), it has been tacitly assumed that some form of suction or magnetic gripper could be used to lift and place the objects during packing. In this case, the *foot-print* of the gripper is assumed to lie within the outer edge of the shapes being manipulated.

Automated material handling systems frequently make use of robotic grippers which have two or more *fingers*. This complicates the problem of packing, since the gripper requires access to objects within a partially packed scene. Therefore any packing strategy must make allowances for the gripper. The grippers worse case position usually (but not always) occurs when the gripper is fully open, just after placing an object in position. The problem of gripper access can be dealt with very effectively, by the simple expedient of overlaying a gripper template on the shape to be packed prior to the application of the geometric packer. The gripper *foot-print* is based on the positions of the fingers in both the open and closed positions. In fact, the convex hull of each of the finger tips in the open and closed positions is formed when computing the composite *foot-print* [2].

In a practical situation care must be taken to ensure that any change in the shape of the objects to be packed, due to squeezing by the robot gripper, does not adversely affect the packing strategy. The same is true of articulated and other hinged objects, such as scissors or pliers, which can change their shape during handling. Again, this type of application constraint could also be dealt with by the introduction of suitable heuristic packing rules, and may also be used as a factor when calculating the gripping position.

The strategy outlined above for working with multi-finger grippers does have the advantage of allowing the shapes to be unpacked from the scene in any order. One possible modification to this approach results in a denser configuration that, in general, can only be automatically unpacked in reverse order. This modification consists of packing each shape, taking the robot *foot-print* into account, but removing the *foot-print* from the scene prior to the application of the next shape.

Of course, many industrial applications do not require that the pieces are unpacked automatically. Certain industrial tasks require manual unpacking, and consideration of the means and the environment of the manual unpacking operation may influence the automatic packing strategies used. For example, if the application requires that items are to be unpacked in a certain order, then this will influence the packing strategy. Consideration must also be given to the means in which the shapes are initially acquired by the robot. If the objects are presented one at a time, then the system can automatically determine the optimal gripper pickup point (robot grasping location) for that object, and proceed to pack it using one of the automated packing strategies outlined previously.

Alternatively, if all the objects to be packed are placed in the field of view at the same time then it may not always be possible for the multi-fingered robot to access the piece it is required to pack. The vision system may have to guide the robot gripper to *push* the object of interest until it is separated enough from the other shapes for the gripper to gain access to the desired pickup points. Also the order in which the shapes are packed may be determined by the order in which the robot can access the objects. Once the shapes have been packed, the robot end-effector can also be used to *nudge* the packed shapes such that a more efficient packing configuration can be achieved.

B. Packing scenes with defective regions.

Any practical automated packing system for use in such industries as leather or timber processing must be able to pack objects into a scene which may contain defective regions. The heuristic packer can readily accommodate defective regions; by simply defining the initial scene to contain a number of holes. Fig. 2(d) illustrates the effect of packing jacket template pieces on to a piece of fabric, prior to cutting. The small blob-like regions indicate the defective areas in the fabric. These defective regions are not to be included in the jacket pieces to be cut. These results illustrate the flexibility of the packing strategies outlined previously.

Conclusion.

The approach outlined in this work is unique in that it combines the strengths of the heuristic approaches to problem solving, with a powerful shape manipulation mechanism, namely mathematical morphology. While it is acknowledged that the application of mathematical morphology to the packing of a small number of arbitrary planar shapes is not new, researchers in this area have concentrated on the mathematical proof of optimal packing configurations, rather than viewing it within the context of the industrial packing problem. But since a mathematical proof that is capable of dealing with a large number of arbitrary shapes may not exist, the application of a heuristic approach that allows the targeting of an efficient rather than an optimal solution, may be a more fruitful line of research.

The second major theme running through this work is the benefits that can be gained by applying a systems engineering approach to complex vision applications. As has been found so often in other applications, the adoption of such an approach is an invaluable aid in the design of industrial vision systems. A systems approach to the design of the packing strategy has been deliberately taken. By taking the systems constraints into account, faster, cheaper solutions may be obtained. It is the authors view that automated packing systems are best designed with regard to such issues as gripper shape, material grain, material defects, etc. It is believed that there is little justification for seeking a unified algorithmic solution that is capable of tackling the totality of packing applications, without human intervention.

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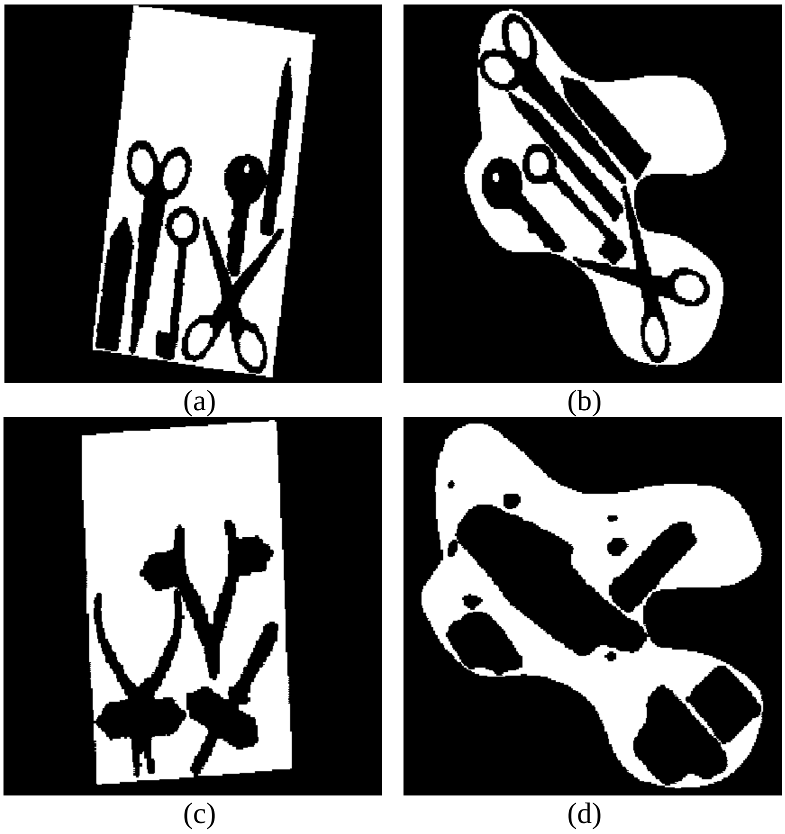

Fig. 2. Automated packing of irregular shapes. (a) A rectangular tray. (b) An irregular scene. (c) Allowing for robot gripper considerations. (d) Cutting jacket template pieces from an irregular fabric segment which contains defective regions.