Defence Science Journal, Vol 46, No. 4, October 1996, pp 243-251

Development of Parallel Algorithms for Computer Vision

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ABSTRACT

Computer vision is an important research area where computationally-intensive and time critical problems need to be solved routinely. This paper described some parallel algorithms for image processing and computational geometry applicable to the field of 'robot vision' which was developed using PACE parallel computer, a loosely coupled message passing MIMD machine, designed and developed at the Advanced Numerical Research & Analyses Group, Hyderabad.

1. INTRODUCTION

The complexity of the problems that can be solved in a cost-effective manner depends on the power of the computer available. Today, very high performance super computers are in increasing demand in the areas of structural analysis, weather prediction, aerodynamic simulation, genetic engineering, computer vision, industrial automation and among many other scientific and engineering disciplines. However, the achievement of high performance depends not only on using a faster and reliable hardware device, but also on major improvements in computer architecture and processing techniques. Most of the computer architectures today are centered around the concept of parallel processing where several processors of smaller capacity are made to work concurrently to achieve high performance. Parallel processing is possible only when the algorithm used is amenable to concurrent computation on more than one processor and one of the processors can control the synchronisation of other processors along with handling of inter-processor communication, when required.

Computer vision and image understanding algorithms employ a variety of methods like signal processing, graph theory and artificial intelligence. The computational time requirements of the algorithms, when executed individually, are prohibitively high and in many practical situations unacceptable. Real-time computation therefore becomes intractable in situations which need to be integrated in a meaningful way to perform a specific task in a reasonable time. For many applications in computer vision, e.g., the interpretation of a scene of resolution 512 × 512 pixels per frame with each pixel of 3 bytes (one byte for each colour and 256 grey levels), the amount of data to be handled per second is several million bytes and the computation required to perform image processing function, such as image transformation, labelling, grouping or motion analysis may be of the order of billion instructions per second. Computer vision is therefore one of the leading research areas, where parallel processing is expected to be significantly beneficial.

2. PROBLEMS

In this paper, the following three problems are described:

- Parallel stereo for 3D depth calculation,
- Parallel 3D convex hull algorithm, and
- Parallel segmentation of colour images.

All these algorithms are parallelised using the PACE parallel machine developed by the Advanced Numerical Research & Analyses Group (ANURAG), Hyderabad. PACE (Processor for Aerodynamic Computations and Evaluation) is a loosely coupled, message passing MIMD machine based on the hypercube architecture and can be configured with a front end processor (FEP) and a variety of number of

Received 15 May 1996
This work was carried out at the Centre for Artificial Intelligence & Robotics, Bangalore.

nodal processors. The number of nodal processors available at the current version are 4, 8, 16, 32, 64 and 128. The machine is currently available in two configurations: PACE using 68030 processors and PACE using SPARC II processors. A configuration of PACE with a MC68030 FEP and eight MC68030 nodal processors was used for the development and testing of the parallel stereo algorithm.

2.1 Parallel Stereo

Stereo vision generates the depth map of a scene by fusing information in images taken from two or more views[1-6]. Stereo is a computationally intensive task. In order to be able to use the stereo information at speeds commensurate with the real-time needs of an assembly robot or an autonomous guided vehicle, either a dedicated hardware or a parallel computer is needed. In this paper, a parallel stereo algorithm is proposed, which uses both edges and regions as features. The algorithm employs an intelligent matching technique which reduces the computational load by reducing the search space for matching.

The different steps in stereo are camera alignment and image acquisition, feature acquisition, image matching and depth computation. Two identical cameras mounted on a stereo arm are used to acquire the stereo pair of images of the scene. The cameras are aligned so that the search space for matching feature points between the left and the right images is reduced from two-dimension to a single-dimension along the horizontal epipolar line.

The present work uses both edge and region as features for stereo correspondence[7]. The edges are detected using the Canny's edge operator[8]. From the camera geometries, the initial set of match points for an edge pixel in the left image consists of all the edge pixels along the epipolar line in the right image. The size of this initial search space for correspondence can be further reduced by using the region information, i.e., information as to which region in the left image the edge pixel belongs to and only considering edge pixels along the same row and in the same region in the right image as candidate points for correspondence. Region information is generated from the images by segmentation and labelling. To calculate the disparity, i.e., the amount of shift between a point in the left image to the corresponding point in the right image, first the individual regions are corresponded using their centroid information. An activity cell of local (11 × 11) neighbourhood around an edge point is used to calculate the disparity. At each of this point a support function is calculated and the point in the cell having the maximum support value is taken as the best match point. Once the disparity at all points in the image is known and the camera parameters like focal length, base-line separation, etc. are known, the depth at that point can be computed using a simple equation based on the geometry of the setup as given below. If d be the disparity of a point then the depth z at that point is given by

$$z = \frac{f * b}{c * d}$$

where,

f - focal length of the camera in cm,

b - base line separation in cm,

d - disparity of the point in pixels, and

c - length in cm that a pixel corresponds to in cm/pixel.

The stereo algorithm were parallelised using the domain decomposition or the single task-multiple data approach[9]. The input domain or the computational load for each parallel task was subdivided based on the number of nodal processors available. Each nodal processor was programmed to execute the same task on different data. The FEP was used to execute all the sequential tasks and also for decomposing data for the parallel tasks. The flow diagram of the parallel stereo is shown in Fig. 1. The timing analysis of the different tasks in stereo shows that the feature acquisition and image matching are the computationally intensive steps of the algorithm. To obtain the maximum speedup and efficiency of parallel stereo, a load balancing scheme is proposed where the number of times this task is performed in the different concurrent processors are made precisely equal. It is found that parallel stereo with load balancing results in greater speedup with the increase in the number of nodal processors. Figure 2 shows the results for a pair of left and right stereo images and their computed depth plot. Figure 3 shows the effect of load balancing with the increase in the number of nodal processors in PACE-8.

2.2 Parallel Convex Hull

Computation of the convex hull of 3D point sets is a frequently occurring problem in the areas of CAD model-based computer vision, robotics and motion planning for assembly. Many algorithms have been

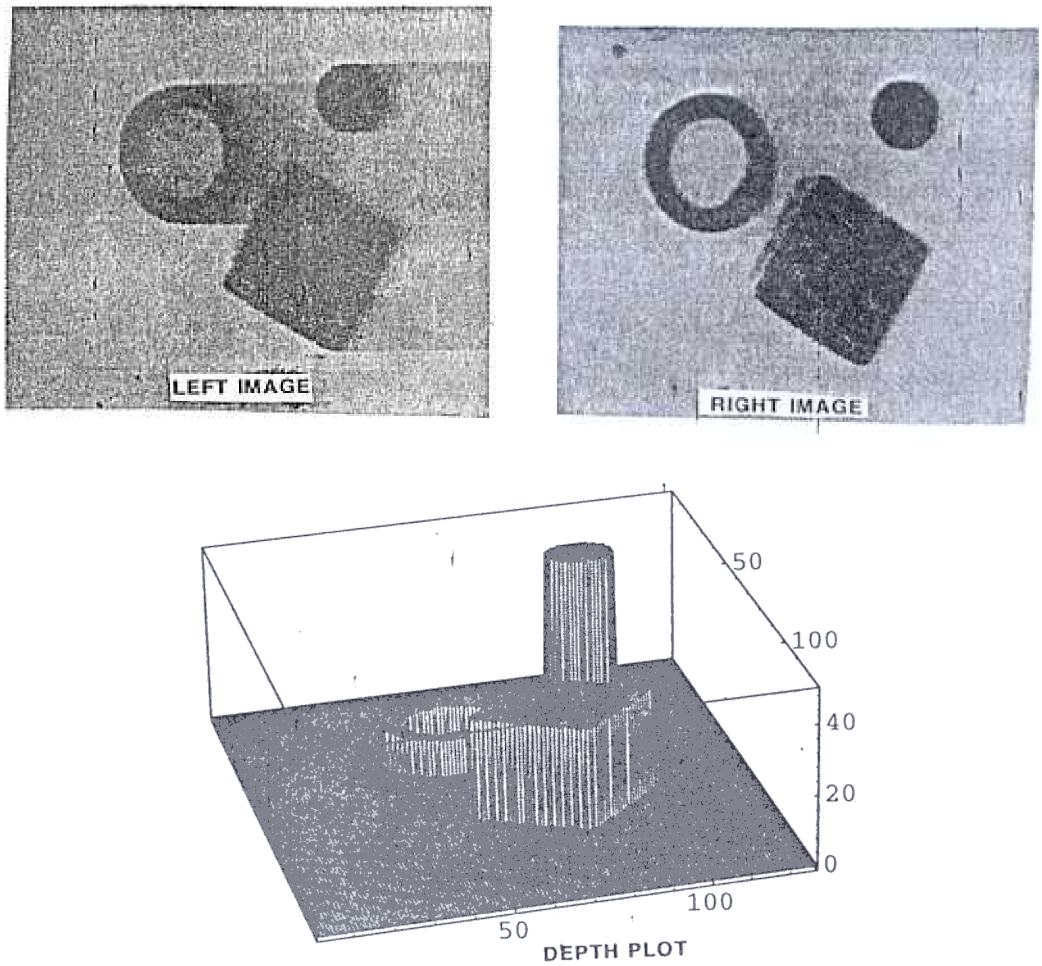

Figure 2. Parallel stereo in PACE parallel machine input: New image.

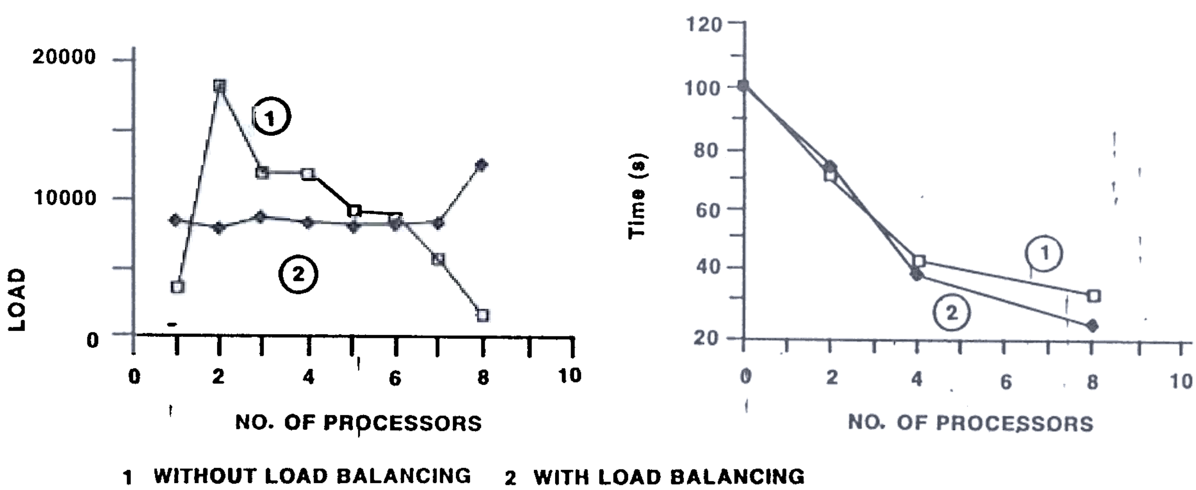

Figure 3. Load analysis and speedup after load balancing.

developed to compute convex hulls in both two-and three-dimensions. In robotic assembly and computer vision applications, the convex hull is used for the purposes of collision detection[10-11], constructing the

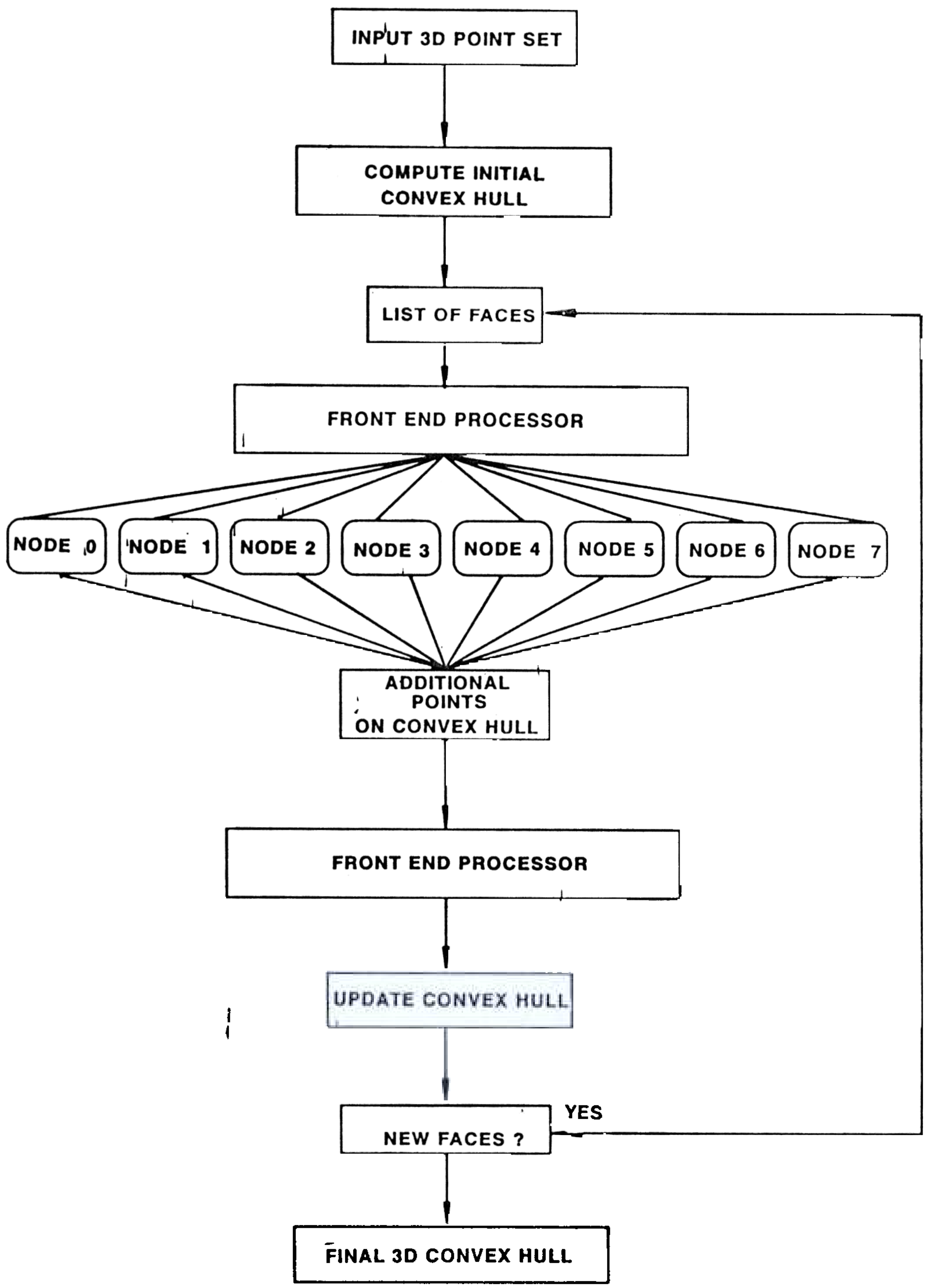

Figure 4. Flow diagram of parallel convex hull.

configuration-space for assembly motion planning[12] and for CAD model-based 3D object recognition and inspection[13].

Typically robots and assemblies are complex, non-convex bodies with many non-polyhedral surfaces. Since efficient algorithms have been developed primarily for the case of convex, polyhedral objects, most robots and vision algorithms utilise a polyhedral-approximation to the actual surfaces. To make the approximation more accurate, a higher resolution and hence a large number of approximating planar surface patches are required. As the accuracy is increased, the size of the polyhedral representation grows rapidly. This leads to large execution times for algorithms which construct the convex hull and also for the application algorithms. The work proposed in this paper describes an algorithm for fast computation of the convex hulls of complex 3D objects[14].

The algorithm first computes a bounding box of the given point sets. One point is chosen in each of the six faces of the bounding box. Any four of these points results in a tetrahedron denoted by diamond which is the initial estimate of the convex hull. On each face of the convex hull, a point is identified which is at maximum perpendicular distance from that face. This point is called an apex point and is guaranteed to lie on the final convex hull. This step is repeated on all the faces of the convex hull and the points which are inside the convex hull are rejected for further consideration.

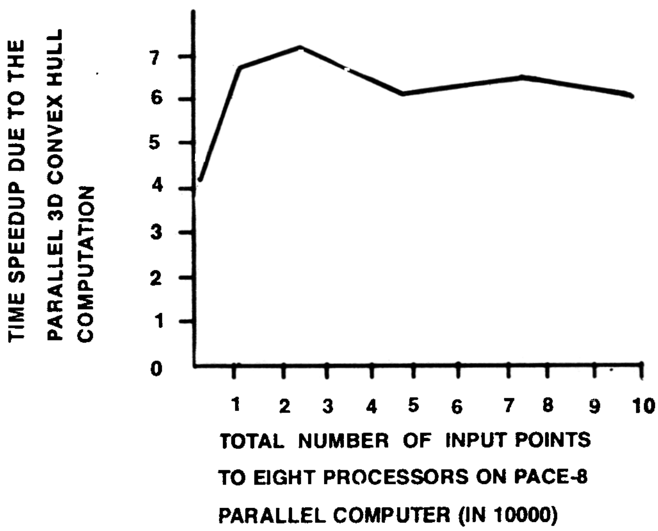

Figure 5. Speedup of parallel convex hull.

The resulting convex hull is the updated convex hull which contain all apex points. Figure 4 shows the flow chart for the computation of parallel 3D convex hull algorithm. Figure 5 shows the speedup of the parallel 3D convex-hull algorithm with eight processors in PACE-8.

2.3 Parallel Segmentation for colour images

Colour is a very special component that adds a new dimension to vision processing. Processing with colour image requires multiple colour features like hue(H), saturation(S), intensity(I), red(R), green(G) and blue(B) to be processed. Typically for an image of size 512 x 512 pixels with 3 bytes and 6 colour features for each pixel, computational requirement is 6 times compared to the gray level image processing.

In this work, a method for parallel segmentation of colour images using region growing method is proposed[15]. The algorithm uses the peaks obtained from the histogram for various colour features. The image regions corresponding to different colours are grown by employing a recursive connectivity algorithm using 4 and 8 neighbourhood connectedness. The best result in segmentation is determined from a study of results with a variety of colour features using different size of colour vectors for region growing. The algorithm has been used to segment the colour geographical maps and remote sensed images obtained from NRSA, Hyderabad. Fig. 6 shows the flow chart of the parallel algorithm

ACKNOWLEDGEMENTS

The author wishes to acknowledge with thanks the contribution of her colleagues Ms. Seethalakshmy, Mr. K. Seetharaman and Dr S. S. Krishnan of the Centre for Artificial Intelligence & Robotics (CAIR), Bangalore, where the work has been carried out. Thanks are also due to Director, NRSA, for providing the remote sensed images. The author also expresses her sincere gratitude to Dr. K. Neelakantan, Director, ANURAG, Hyderabad, for providing support for running the PACE machine at CAIR. The author thanks Director, Aeronautical Development Establishment, Bangalore, for his kind permission to publish this paper.

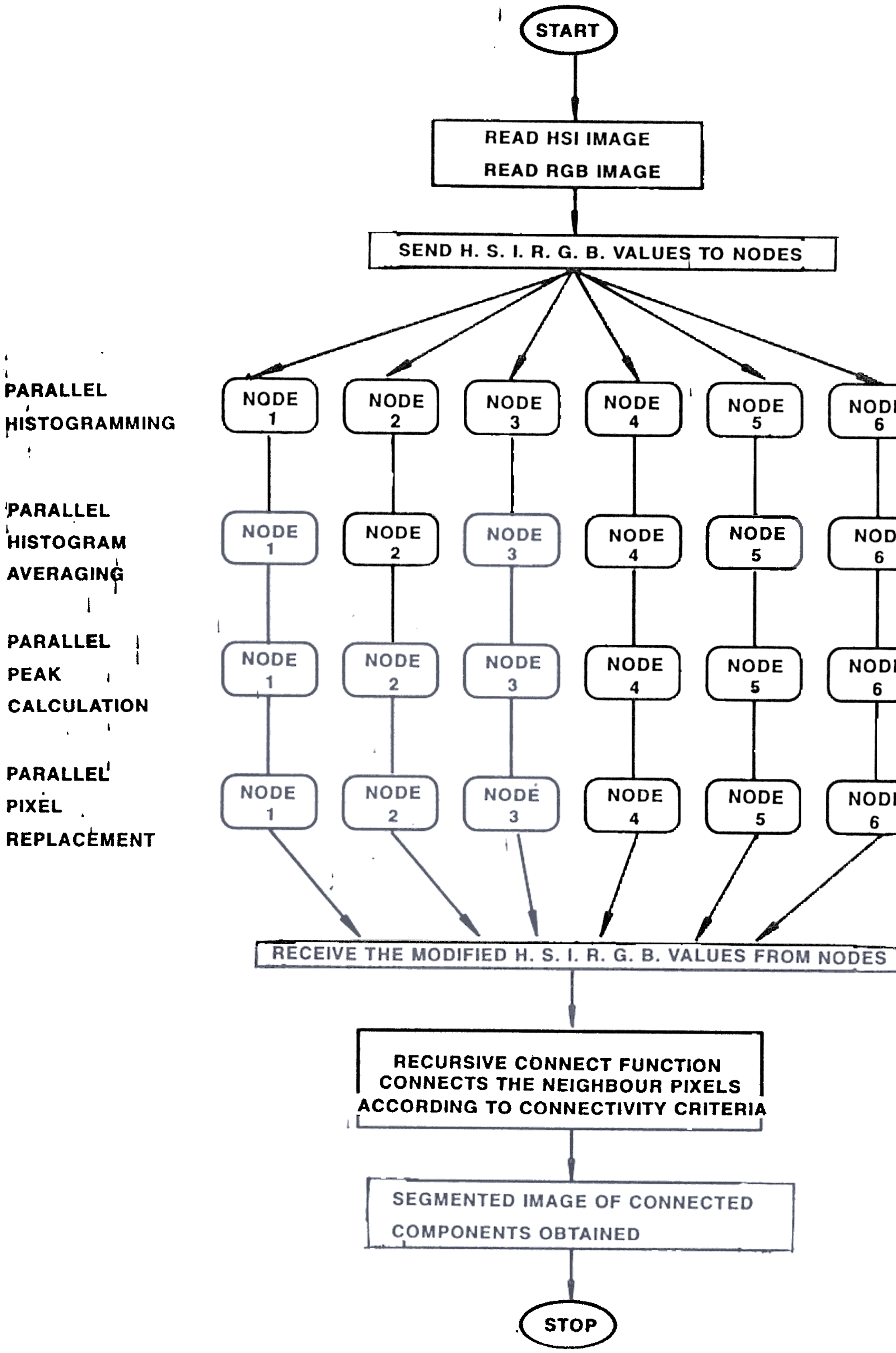

Figure 6. Flow diagram of parallel colour segmentation algorithm.

Figure 7(a). Input image of Rajahmundry area.

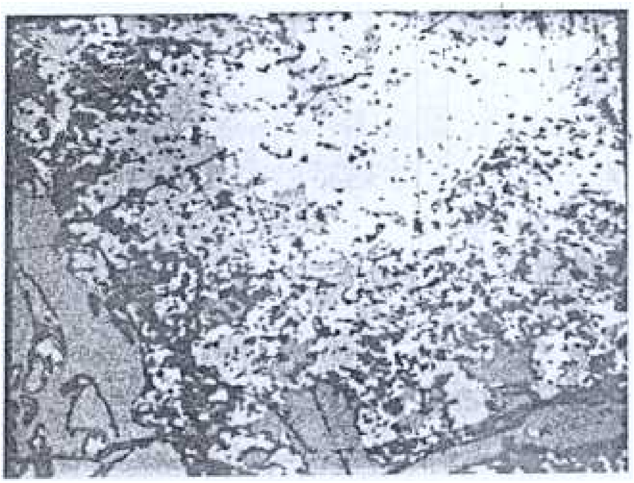

Figure 7(b). Output image of Rajahmundry area yellow-cashew plantation, magenta-qarries, green-paddy region, red at the top-tobacco light blue-sand area, red-godavari river, purple at the top-water logged area.

Figure 8(a). Input image of Hyderabad lake area.

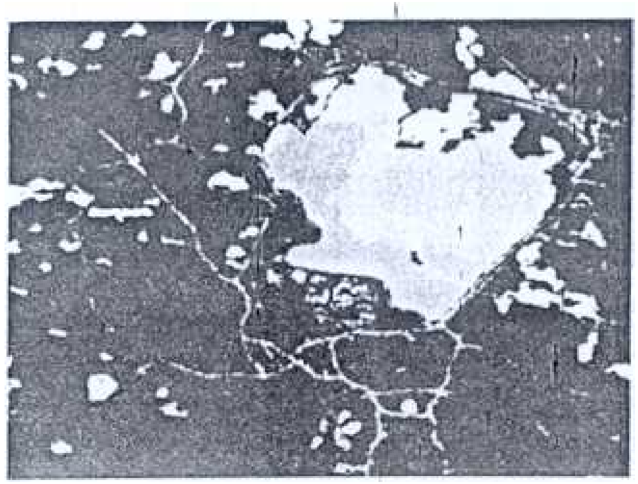

Figure 8(b). Output image of Hyderabad lake area: Green-shallow water, pink-shallow water with slight vegetation, violet-deep water, yellow-parks and vegetation cover, red-large human build up, blue-some prominent roads.

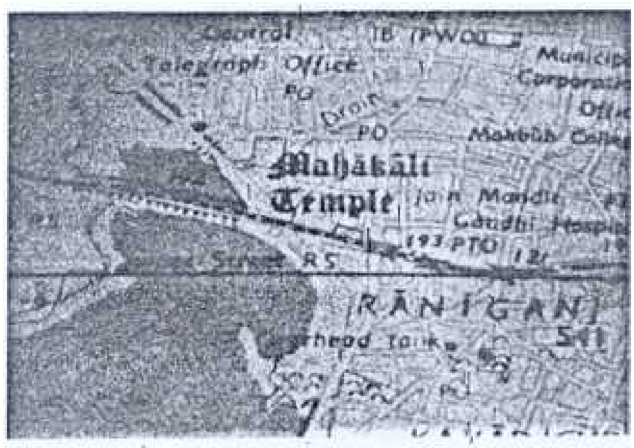

Figure 9(a). Input map of Hyderabad area.

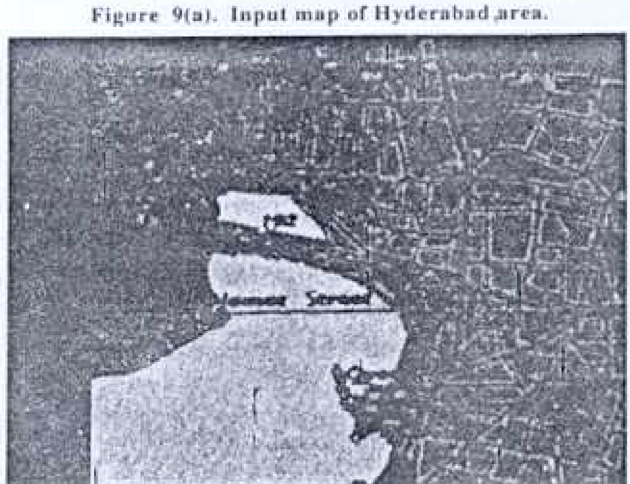

Figure 9(b). Output map of Hyderabad area : Red-lake, blue-buildings.

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