Empirical analysis of a moving head disc model with two heads separated by a fixed number of tracks

I. P. Paget† and R. T. Wood

Computer Science Department, Brunel University, Uxbridge, UB8 3PH, UK

This paper discusses an empirical study of a moving head disc system which has two heads on each calliper arm, separated by a fixed number of tracks. The behaviour of the system was examined by means of a simulation model operating with a uniform random request sequence. Two derivatives of the shortest seek time algorithm were investigated and for each the optimal head separation was found as a function of request queue length. It was found that when both heads are constrained to remain within the recording region, the optimal head separation approximates to half the distance between the innermost and outermost tracks. If either head is allowed to go outside the recording region, the optimal head separation was found to be a linearly reducing function of queue length. The former algorithm gives the best performance in minimising seek times.

(Received August 1980)

1. Introduction

Various authors have studied disc head positioning algorithms (Coffman *et al.*, 1972; Denning, 1967; Frank, 1969; Gotleib and Macewen, 1973; Siskind and Rosenhead, 1976; Waters, 1975) and conclude that the most acceptable performance is obtained from the SCAN algorithms. These move the heads in a consistent direction between servicing queued requests until there are no further requests in that direction. The RASTER SCAN algorithm then skips back to the most distant track requested in the queue, while SEE SAW SCAN simply reverses the scan direction and services requests on both traverses of the heads.

The shortest seek time (SST) algorithm simply selects the queued request which minimises head movement. While this algorithm produces the highest service rate, it is unacceptable in practice because the head tends to remain close to the central region and requests for the outermost and innermost tracks are disadvantaged. This bias in the algorithm was expected to occur with the two headed system, but not to the same extent. It was reasoned that if the head separation were approximately $N/2$ tracks, then the presence of one head near the centre implied that the other head was in one of the outer regions. The bias exhibited might be assumed to be toward the central tracks, or toward both outer regions as well as the centre. In any case, it was not clear as to what the optimum head separation might be when the modified SST algorithm was used with two heads servicing each surface.

The performance of the two headed system is easily predicted when either of the SCAN algorithms is used. The heads are then ideally separated by $N/2$ tracks and each head is constrained to serve half of the tracks. The maximum head traverse is then $(N/2) - 1$ tracks and the system is isomorphic with a single headed drive of twice as many surfaces. Several manufacturers have recently introduced drives with two heads per surface known to be separated in a manner similar to that suggested in this paper: Sperry Univac 8450 and 8470 models, and Burroughs FD 210 Fixed Disc series.

2. The simulation model

A single surface disc was simulated with 800 tracks. The chosen model approximated to those mentioned above and it was felt that the correct starting point for a theoretical analysis of this problem would be for a single surface device. The requests comprised uniform random track address and the queue was kept full at all times. This arrival pattern was not intended to accurately reflect any practical situation but to provide a controlled loading on the disc which could be of value in initiating a theoretical study.

Some experiments were carried out with a single element request queue and a single head system in order to simulate the 'first come first served' (FCFS) situation so that the model could be validated against known theory. The population mean and variance of the head movement distance are given by:

$$\mu_H = \frac{(N-1)(N+1)}{3N} \qquad \sigma^2_H = \frac{(N-1)(N+1)(N^2+2)}{18N^2}$$

Fig. 1 shows a typical empirical distribution for head movement resulting from a run of 5000 requests. A χ^2 goodness of fit test shows a significant correlation with the expected triangular distribution.

Fig. 2 shows the mean time waiting in the queue against track number when the queue was five elements and the SST algorithm was used. The bias given to the central region is clearly evident from this diagram.

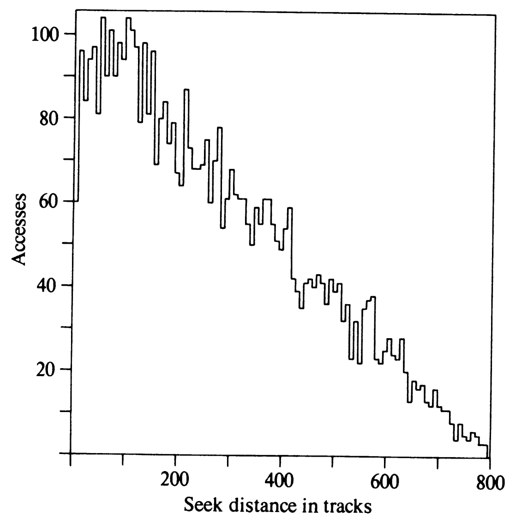


Fig. 1 Histogram of seek distance for single head, uniform random requests

†Present address: Faculty of Mathematical Sciences, University of Texas at Dallas, PO Box 688, Richardson, Texas 75080, USA.

CCC-0010-4620/81/0024-0339 $02.00

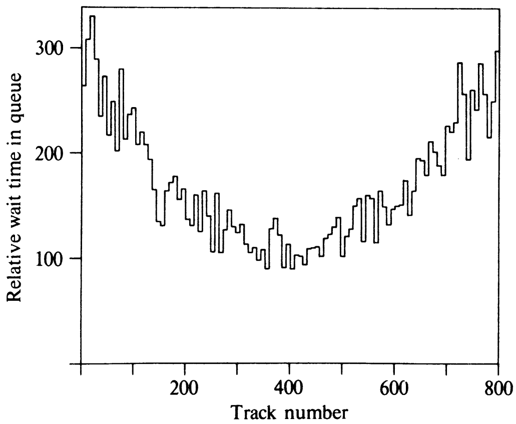


Fig. 2 Relative wait time in queue against track number with five element queue and a single head

3. Two heads

Having gained confidence with the model, a series of experiments was conducted to deduce empirically the optimum head separation. Two versions of the SST algorithm were investigated. In SST1 the queue was scanned for the request which minimised arm movement without any regard for the resulting position of the other head. It was clear that each head would occasionally be moved outside the recording region. Indeed, the maximum head traverse would be N-1 tracks. While this algorithm may not be sensible from an engineering point of view, it was thought valid to investigate its performance.

The SST2 algorithm also selected the request which minimised head movement, but with the overriding constraint that both heads remain within the recording region. Head 1, therefore, serves tracks 0 to $N/2$ and head 2 serves tracks $(N/2) + 1$ to $N - 1$. Head separations of greater than $N/2$ are therefore not possible. **Fig. 3** shows mean seek distance against head separation for both algorithms with request queue size (Q) as a parameter. The model was designed to facilitate head

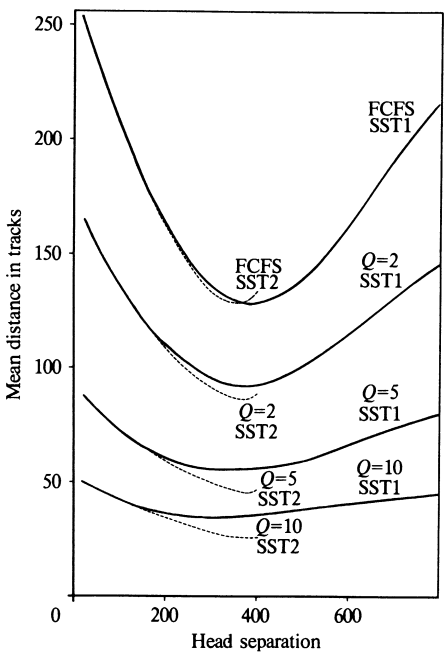
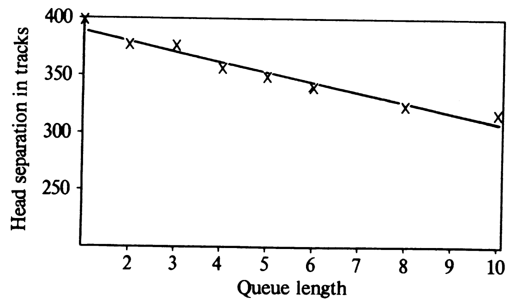


Fig. 3 Seek distance vs head separation for various queue sizes. SST1—unrestricted movement; SST2—restricted movement



Equation of line
$y = \hat{a}_0 + \hat{a}_1 x$
where $\hat{a}_0 = 399{\cdot}1$ and $\hat{a}_1 = -8{\cdot}88$.

Fig. 4 Optimum head separation against queue length for SST1

separations of greater than 800 tracks for the SST1 algorithm in order to investigate the limiting behaviour as the model degenerated to one of a single head. The run length of each trial was 5000 requests, which enabled 95% confidence intervals to be kept to approximately ± 3 tracks. It is seen that the performance becomes much less sensitive to head separation when the queue is large. The optimum head separation for SST1 appears to reduce from $N/2$ towards $N/3$ as the queue length is increased. A least-squares fit to a quadratic was employed on points close to the minima in order to estimate the positions of the minima from the coefficients of the

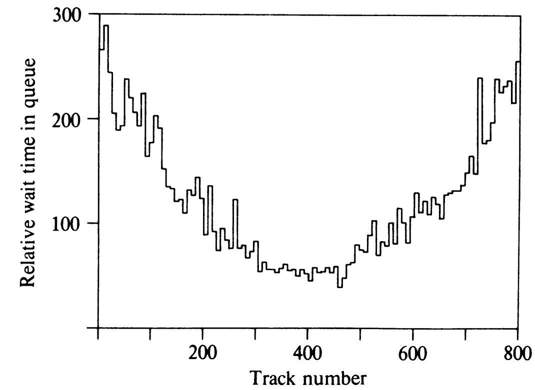


Fig. 5 Relative wait time in queue against track number with five element queue and head separation of 267 tracks—SST1 algorithm

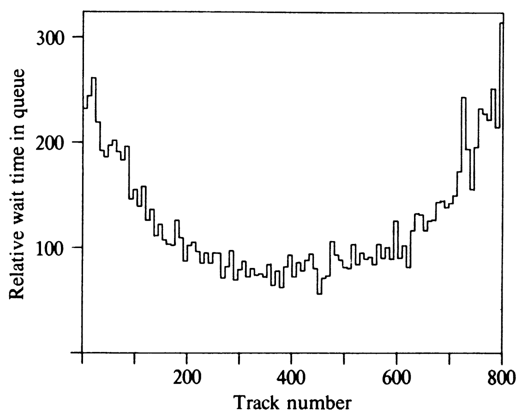


Fig. 6 Relative wait time in queue against track number with five element queue and head separation of 400 tracks—SST1 algorithm

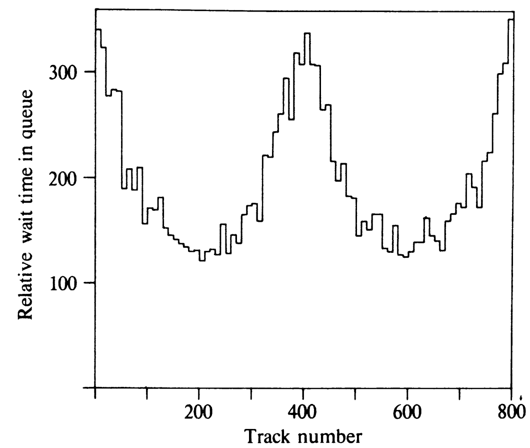


Fig. 7 Relative wait time in queue against track number with two element queue and head separation of 400 tracks—SST2 algorithm

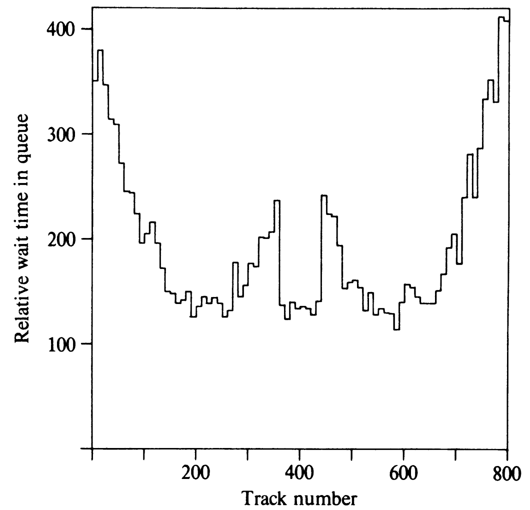


Fig. 8 Relative wait time in queue against track number with two element queue and head separation of 360 tracks—SST2 algorithm

quadratics. **Fig. 4** shows that the optimum head separation reduces approximately linearly with queue length. The linear model suggested here seems quite appropriate for relatively small queues as expected in practice.

For the SST2 algorithm the optimum separation is seen to be close to $N/2$ and to approach it as the queue length is increased. The loss in performance when a separation of $N/2$ tracks is employed with SST2 is less than 3% for all queue lengths investigated. A head separation of $N/2$ tracks gives almost optimum performance and provides designers with the option of choosing one of the SCAN algorithms.

Both algorithms exhibit considerable bias as seen in Fig. 2 and **Figs. 5–8.** With SST1 the bias is less pronounced when the separation between the heads is increased from the optimal value to $N/2$. This is seen in Fig. 6 where the central region between track numbers 200 and 600 is almost flat. The degradation in mean seek distance in employing a separation of $N/2$ tracks is less than 2%. These results indicate that the best

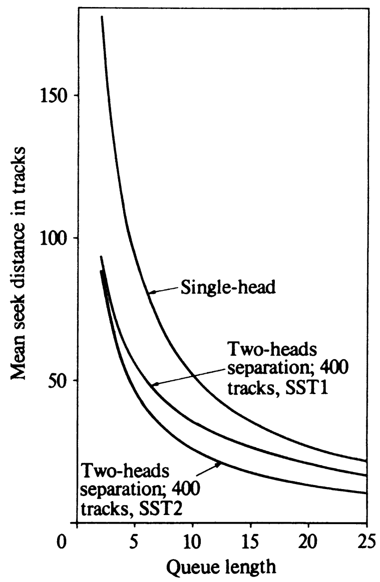


Fig. 9 Mean seek distance against queue length

overall performance is obtained with a separation of $N/2$ tracks with the SST1 algorithm.

Fig. 7 shows the mean queue time against track number for the SST2 algorithm and a head separation of $N/2$ tracks. The bias exhibited by the restricted head movement algorithm SST2 appears in two regions symmetrically placed about the centre. By comparing Fig. 7 with Fig. 2, it is seen that the SST2 algorithm with head separation of $N/2$ tracks behaves exactly like a single head system with half as many tracks. When the head separation is reduced to the optimum value of 360 tracks, three heavily favoured regions appear, as illustrated in Fig. 8. It would appear that the lower mean head movement obtained with SST2 is secured at the expense of added bias towards two or three regions. A separation of $N/2$ tracks would seem to give the best overall performance with the SST2 algorithm, irrespective of queue length, and hence disc loading.

Fig. 9 shows the mean seek time against queue length for the single and double headed systems. It is seen that the additional head halves the mean head movement when the queue comprises just one request (FCFS). As the queue length is increased, the performance of SST1 and of a single head system approach the same limit. The performance of SST2 also approaches this limit, the mean head movement distance remaining approximately half of that for the single head system. At some point the latency delay will begin to dominate the service time and thus considerably reduce the advantage of the two head system.

4. Conclusions

The results of this study indicate that a head separation of $N/2$ tracks would give the overall best performance. It was found that with SST1 the optimum head separation reduced linearly with queue length. The loss in performance when a separation of $N/2$ tracks was employed was less than 2%. With SST2 a separation of $N/2$ tracks is sufficiently close to the optimum for all queue lengths.

References

COFFMAN, E. G., KLIMKO, L. A., and RYAN, B. (1972). Analysis of scanning policies for reducing disc seek times, *SIAM Journal on Computing*, Vol. 1, pp. 269–279.

DENNING, P. J. (1967). Effects of scheduling on file memory operation, in *Proceedings of the American Federation of Information Processing Societies Spring Joint Computer Conference*, Vol. 30, pp. 9–21.

Frank, H. (1969). Analysis and optimisation of disc storage devices for time-sharing systems, *Journal of the ANM*, Vol. 16, pp. 602–620.
Gotleib, C. C., and Macewen, G. H. (1973). Performance of movable-head disc storage devices, *Journal of the ACM*, Vol. 20, pp. 601–623.
Siskind, V., and Rosenhead, J. (1976). Seek times for disc file processing: some results from probability theory, *The Computer Journal*, Vol. 19 No. 4, pp. 301–305.
Waters, S. J. (1975). Estimating magnetic disc seeks, *The Computer Journal*, Vol. 18 No. 1, pp. 12–17.

Book reviews

Computers in Critical Care and Pulmonary Medicine, edited by S. Nair, 1980; 427 pages. (*Plenum Press*, \$47·40)

This volume is a collection of papers of the first international meeting in critical care and pulmonary medicine, held at Norwalk Hospital, Yale University, School of Medicine in 1979. It is a collection of 38 papers covering various aspects of the application of computerised information systems sometimes used to guide and control both care and therapy with the objective of minimising human intervention. Thus, the importance of good systems analysis and design cannot be overstated.

Indeed, some of the papers dealing with artificial ventilation control and closed loop therapy emphasise the importance of adequate systems analysis and design before going to develop their systems which support intensive types of care. Only in this way can serious mistakes be avoided. Other papers are devoted to different ways of organising appropriate measurements and presenting the data to care staff using new and different monitoring facilities. Unfortunately, the terminology used is not always compatible and some familiarity with the fields of knowledge under consideration is necessary by the reader.

It is a rather gregarious collection of many different experiments in critical care from many countries. It will be of major interest to those involved in the field that demands the co-operation of biochemical engineers and those engaged in this difficult, arduous and specialised field of health care. The advances in monitoring and controlling care by computerised systems are now becoming significant. The widespread use of information processing implied by the volume illustrates that it can solve existing difficult problems. It is not a book for the unitiated but should have a place in medical libraries.

J. Anderson (London)

Hardware/Software Design of Digital Systems, by R. E. H. Bywater, 1981; 477 pages. (*Prentice-Hall*, £15·95)

To quote from the Preface: 'This book has been written as a second-level text on computer engineering. It is designed for students who already possess some elementary knowledge of digital computers and some familiarity with computer programming. It has also been prepared with practising digital system engineers in mind and provides a reference for design approaches.' It would be hard to formulate a better description of the book: like that of so much of the material in it, the author's description is a precise and accurate one.

On commencing reading the book for the first time the reader might well suppose it is just another treatise on computer engineering but soon finds out that it is not—in fact the title is as apt as the description in the preface. The author has spent much time and gained great experience in designing machines like hybrid computers and D.D.As. The book is written for designers of digital systems which may well contain conventional computers or parts of them. Hence the test deals quite cursorily with the conventional elementary material of computer engineering but deals in depth with refinements to it. It deals, for instance, with microprocessors comparatively, since these might well be components in a specially designed digital system. It deals with simple arithmetic units cursorily but it deals in depth with techniques for gaining speed or efficiency. Thus it is indeed a 'second-level' test, and it is a useful one, and should be read by system designers and all others who take an earnest interest in digital computer design. There is much that is factual in the text—it is a thick book—but there is also a wealth of valuable counsel based on hard experience.

B. S. Walker (Reading)

Advances in Digital Image Processing: Theory, Application, Implementation, edited by P. Stucki, 1980; 332 pages. (*Plenum*, \$37.50)

This book contains 15 papers delivered at an international symposium on digital image processing held at Bad Neuenahr, FRG during 26–28 September 1979 and is one of a series of books in the *IBM Research Symposia* series. The book is divided into four main areas: general, theory, application and implementation. The first section gives two papers which describe the development of photography in image science, and future trends in computer graphics and image processing in general. The theory section consists of three papers which are more mathematical, covering signal analysis applied to images, coding of TV signals and digital image analysis. The applications section of the book was found to be the most interesting. Topics here included biomedical image processing, x-ray image processing, Landsat image processing, document reproduction and sampling, computer graphics and automatic vision for industrial applications. Several colour plates are also provided in this section. The final section on implementation comprises four papers describing the technicalities of hardware image processing systems, viz. distributed, parallel, vector-array and other high speed signal processors.

The book is well illustrated and strikes a useful balance between mathematical theory and hardware implementation of digital techniques. In many edited books of this kind, which present a number of papers contributed by several authors, there tends to be a large amount of overlap and also areas which are not covered at all. Another problem is the non-standardisation of nomenclature throughout the book which can be confusing for first time readers. Certainly the book does provide the reader with some insight into the advances in image processing, but the subject would probably be better served if more papers had been included or if the book had concentrated on fewer topical areas, considering the vast scope of the subject.

N. P. Wootton (London)

Search Theory and Applications, edited by K. B. Haley and L. D. Stone, 1980; 277 pages. (*Plenum*, \$42·00 (outside USA))

This book comprises most of the papers presented at working group and plenary sessions at the NATO Advanced Research Institute on Search Theory and Applications held in Portugal in March 1979. Their content covers a wide academic range, from theoretical, involving degree-level mathematics, to general and non-mathematical (e.g. the search for radioactive fragments of the Russian Cosmos satellite which disintegrated over frozen N.W. Canada). Many discuss the optimal allocation of existing search resources in the light of the available detector characteristics and the most up-to-date information; thus two papers refer to the CASP (computer-assisted search planning) system, now in use by the US Coast Guard Service, which produces an irregular two-dimensional probability map of a target's location resulting from a simulation using input scenario data and blank searches to date. The difficult economic and ethical problems of what level of resource to employ at any stage of a search are mostly not considered.

The book hopes to demonstrate that search theory unifies problems in many different fields; thus one short paper on industrial applications presents an excellent account of applying two solutions in search theory to practical problems in quality-control testing, detecting defective components and managing a research and development project.

The format is photographed typescript: minor production faults, such as different apostrophes and alternating dark and light print (which appear to be due to revisions), should have been avoidable. Overall, when used judiciously, a book to whet the appetite.

R. E. Thomas (Stirling)