TABLE V

CRITERION	EFFECTIVE WEIGHTS	ADJUSTING FACTOR	ADJUSTED EFFECTIVE WEIGHTS	TOTAL WORTH SCORES X	Y
B_1	0.5969	0.95	0.6164	0.3822	0.3267
C_1	0.0144	0.90	0.0141	0.0085	0.0099
C_2	0.0817	0.80	0.0710	0.0497	0.0568
C_3	0.2220	0.95	0.2293		
C_4	0.0277	0.85	0.0256	0.0218	0.0192
B_3	0.0573	0.70	0.0436	0.0262	0.0283
			TOTAL	0.4884	0.4409

is to the various offers by the aircraft companies in the area of technology transfer. Based on the worth scores for the fleet, we conclude that, *whenever the worth scores of technology transfer objective of fleet Y less the worth score of technology transfer objective of fleet X is greater than or equal to 0.2072, Y is the preferred fleet. Otherwise, X is the preferred one*. Finally, it is worth mentioning that sensitivity analysis on the preferred fleet can be easily conducted on different sets of worth scores as well as varying degrees of weighting factors associated with the objectives.

Conclusion

In this correspondence we have developed a model to guide the military planners on the choice of a transport aircraft fleet. The model also takes into consideration the social and economic factors that are affecting the decision process. Due to the fact that the airlift capability of the fleet is impossible to model mathematically, simulation tools are employed. Worth assessment procedure is then applied to establish a preference relationship between various aircraft fleets.

However, it is apparent that our model is just a way of formalizing common sense. It gives no magical formulas for correct decisions. In fact, the model forces the decisionmaker to rely more strongly than ever on his own judgments but does give him a framework in which to work, a framework that is adaptable in principle to all military decision problems.

References

[1] C. J. Hitch and R. N. McKean, *The Economics of Defence in Nuclear Age*. Cambridge, MA: Harvard Univ. Press, 1960.

[2] K. Y. K. Ng, "On military transport aircraft fleet planning," in *Proc. Tenth Ann. Pittsburgh Conf. Modelling and Simulation*, vol. 10, part 5, 1979, pp. 1941–1947.

[3] A. P. Sage, *Methodology for Large-Scale Systems*. New York: McGraw-Hill, 1977.

[4] T. L. Saaty, "A scaling method for priorities in hierarchical structures," *J. Math. Psych.*, vol. 15, pp. 234–281, June 1977.

[5] ——, "Modelling unstructured decision problems-The theory of analytical hierarchies," *Math Comput. Simulation*, pp. 147–158, vol 20, 1978.

[6] ——, "Applications of analytical hierarchies," *Math Comput. Simulation*, vol. 21, pp. 1–20, 1979.

[7] E. S. Quade, "Military systems," in *Handbook of Operations Research, Models and Applications*, vol. 2, J. J. Moder and S. E. Elmagbraby, Eds. New York: Van Nostrand, 1978, pp. 503–534.

[8] Operational Res. and Analysis Establishment, Dep. Nat. Defence, Canada, ORAE Project Report PR77.

[9] K. Y. K. Ng, and J. G. Moscrip, A Computer Model for the Evaluation of Military Transport Aircraft, III Symposium uber Operations Research, Universitat Mannheim, Sept. 1978.

[10] R. L. Keeney and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. New York: Wiley, 1976.

A Hierarchical Representation of Citation Relationships

SADAAKI MIYAMOTO AND KAZUHIKO NAKAYAMA

Abstract— Citation relationships among scientific journals as a hierarchical graph, in order that bibliographic information may become available in a compact form for readers of periodicals, is represented. The citation frequency matrix among journals in instrumentation/control engineering is derived by using the data base, *Science Citation Index* [7]. The frequency matrix is transformed into a columnwise normalized matrix which is considered to be a representation of the amount of influences between arbitrary pairs of journals. Then, two thresholds are applied in order to derive the arcs of the graph. One threshold is a level of significance, i.e., an influence below this level is negligible. The other threshold is the ratio of influence between an arbitrary pair of journals: if the ratio of influence between a particular pair of journals exceeds this threshold, a directed arc is drawn. The resulting graph is portrayed by a hierarchical configuration so that most arcs have upward directions. Moreover an agglomerative clustering based on a symmetrization of the citation frequency is performed and several groups are extracted. The directed graph and the groups are represented in a figure, showing information flows and substructures of this field of engineering.

I. Introduction

Remarkable progress has been recently made in the retrieval of scientific information by using high-speed digital computers and their storage devices. Namely, today the data bases of bibliographic information have millions of scientific articles and on-line utilization has become possible.

With the development of these large-scale data bases, there have arisen several attempts to analyze and synthesize the bibliographic information in order to clarify the present state of sciences and their movements [1]–[4]. These attempts have a remarkable feature: they use new techniques of statistics such as clustering and multidimensional scaling [1], other than traditional descriptive statistics.

These graphical methods are effectively used to simplify the internal structure of a system in order to apply human intuition and insight into the complex. For example, the clustering tech-

Manuscript received June 23, 1980, revised August 22, 1980.

The authors are with the Scientific Information Processing Center, University of Tsukuba, Sakura-mura, Niihari-gun, Ibaraki-ken 305, Japan.

nique summarizes the elements of the system and generates subgroups. The procedure is as follows: a) extract elements for clustering from the total system, b) compute the measure of similarity between a pair of elements, c) sum up elements which are mutually similar and generate groups, and d) give appropriate interpretations to the groups and explain the structure of the system.

Note that the measure of similarity $s(i, j)$ (i, j:elements to be clustered) must satisfy the symmetrical property:

$$s(i, j)=s(j, i).$$

On the other hand, there are occasions in which the mutual interaction of elements is naturally defined but not symmetrical. That is, if the interactions between i and j are $t(i, j)$ and $t(j, i)$, then

$$t(i, j)\neq t(j, i).$$

This correspondence is mainly concerned with the development of a method for a visual representation of this nonsymmetrical interaction. For this purpose a directed graph is used, i.e., if a scale of the nonsymmetricity exceeds a fixed level, a directed arc is drawn between the corresponding elements. The procedure is a) transformation from the measure of interaction into a scale of nonsymmetricity, b) derivation of the directed graph by defining the arcs, and c) visual representation of the graph by hierarchical configuration of the nodes.

This method is applied to citation relationships between scientific journals. In this case a nonsymmetrical relation really exists, since even if journal A frequently cites journal B, B does not always have many citations of A.

The data base *Science Citation Index* is a good source for this purpose, since it has data of citation for individual articles. We selected 34 journals of instrumentation/control engineering and constructed a directed graph based on the citation frequencies using the above procedure. Moreover by symmetrizing the interactions of citation, we generated several groups by an agglomerative clustering [5]. The directed graph and the groups are represented on one figure, which clarifies the information flows and the substructures in this field of engineering.

II. Nonsymmetrical Interaction

Let $S=\{1,2,\cdots,n\}$ be a set of scientific journals, on which a $n\times n$ matrix $T=(t_{ij})$ of mutual citation frequencies and a n-vector $u=(u_j)$ of total citation frequencies are assumed to be given. The element t_{ij} means the frequency of jth journal's references to ith journal, and u_j is the frequency of total references of jth journal. Note that

$$\sum_{i=1}^{n} t_{ij} \leqslant u_j$$

but the equality does not always hold, since the journals $1, 2,\cdots, n$ do not exhaust all the scientific journals in general.

We shall derive a graph $G=(E,V)$, where the nodes $E=\{1,2,\cdots,n\}$ and V is the set of arcs. Let us derive the adjacency matrix A of G. First, we transform T into a normalized matrix $P=(p_{ij})$ $1\leqslant i,j\leqslant n$ whose column sums are less than or equal to unity. That is,

$$p_{ij}=\frac{t_{ij}}{u_j}.$$

The element p_{ij} represents the ratio of i's influence on j to the total influence on j, and we call it an influence measure.

The arcs of G are determined by comparing two influence measures p_{ij} and p_{ji} between i and j. For this purpose, we use two thresholds (α, β) $(0<\alpha<1, \beta>1)$, which means that

1) the influence p below α is negligible,
2) the arc $(\rightarrow)$ is drawn if the ratio p_{ij}/p_{ji} exceeds β, where $p_{ij}>p_{ji}$, and
3) even if p_{ij}/p_{ji} does not exceed β, we draw a special arc $(\leftrightarrow)$ provided that both p_{ji} and p_{ij} exceed α.

More precisely, the adjacency matrix A is determined as follows:

a) $a_{ij}=1, a_{ji}=0$ $(i\rightarrow j)$

$$\Leftrightarrow p_{ij}\geqslant\alpha,\ p_{ij}>\beta p_{ji},$$

b) $a_{ij}=a_{ji}=1$ $(i\leftrightarrow j)$

$$\Leftrightarrow p_{ij}\geqslant\alpha,\ p_{ji}\geqslant\alpha,\ \frac{1}{\beta}\leqslant\frac{p_{ij}}{p_{ji}}\leqslant\beta,$$

c) $a_{ij}=a_{ji}=0$, otherwise.

Our next step is to portray the graph G. That is, we must specify the configuration of it. For this, a hierarchical configuration such as is adopted in interpretive structural modeling [6] is used. Namely, the positions of the nodes are determined so that the arcs have upward directions. For this purpose a partial ordering of a graph is used so that a node is "higher than" another node if and only if the former is reachable from the latter. If the transitive law ($i\rightarrow j$, $j\rightarrow k$ means $i\rightarrow k$) holds, then the hierarchical positioning is possible. Unfortunately, in our case a loop of arcs $(i\rightarrow j\rightarrow\cdots\rightarrow k\rightarrow i)$ may occur; moreover two-sided arcs $(\leftrightarrow)$ may arise. Therefore we consider a "partial" configuration, which consists of

1) the transformation of the original graph G into a quotient graph $\tilde{G}=(\tilde{E},\tilde{V})$ on which a partial ordering is possible, and
2) the configuration of the quotient graph according to the partial ordering.

An element $\tilde{p}$ of the quotient graph $\tilde{G}$ is a set of elements of the original graph G which are mutually reachable. That is, for any e, $f\in\tilde{p}$, there exists a sequence of elements $e_1, e_2,\cdots, e_\kappa, f_1, f_2,\cdots, f_l\in E$, such that

$$e\rightarrow e_1\rightarrow\cdots\rightarrow e_\kappa\rightarrow f$$

and

$$f\rightarrow f_1\rightarrow\cdots\rightarrow f_l\rightarrow e.$$

Note that a two-sided arc $(e\leftrightarrow f)$ is interpreted as two arcs $e\rightarrow f$ and $f\rightarrow e$. The arcs of G is defined by the following: for $\tilde{p}$, $\tilde{q}\in\tilde{E}$, $\tilde{p}\rightarrow\tilde{q}$ if and only if there exist $e\in\tilde{p}$ and $f\in\tilde{q}$ such that $e\rightarrow f$ in G.

If the ordering $\prec$ in $\tilde{G}$ is defined as such, for $\tilde{p}$, $\tilde{q}\in E$, $\tilde{p}\prec\tilde{q}$ if and only if $\tilde{q}$ is reachable from $\tilde{p}$, then it is easy to prove that this relation is indeed a partial order: it is sufficient to show that $\prec$ satisfies asymmetric law and transitive law.

This algorithm specifies the vertical position of the nodes in $\tilde{G}$, whereas the configuration of the elements of the original graph in the same class $\tilde{p}\in\tilde{E}$ is not possible. Therefore we have a considerable degree of freedom in the determination of the configuration.

III. Citation Relationships

Our example is based on the data base Science Citation Index. This data base has about 500 000 records annually for over 2600 journals from all scientific disciplines [7]. Each record has the title of an article, the authors, the journal, its citations, and so on. Since a citation contains the title of a cited journal, we can derive a citation frequency matrix of scientific journals.

We extract records whose journals belong to instrumentation/control engineering according to the classification of the Institute for Scientific Information: using the data for 1977, the extracted 34 journals are listed in Table I. For each record, its cited articles are used to determine cited journals, then citing and cited frequencies are determined. A part of the resulting

TABLE I
THIRTY-FOUR JOURNALS IN INSTRUMENTATION/CONTROL ENGINEERING

Titles of journals	(abbreviations)	Numbers of source articles
Applied Spectroscopy Reviews	(APPL SP REV)	9
Applied Spectroscopy	(APPL SPECTR)	127
ATM Messtechnische Praxis	(ATM MESS PR)	22
Australian Journal of Instrumentation & Control	(AUST J INST)	14
Automation and Remote Control USSR	(AUT REMOT R)	273
Automatica	(AUTOMATICA)	43
Automatisme	(AUTOMATISME)	47
Biomedical Engineering	(BIOMED ENG)	64
Chemical Instrumentation	(CHEM INSTR)	18
Control and Instrumentation	(CONTR INSTR)	74
Control Engineering	(CONTROL ENG)	98
F&M-Feinwerktechnik & Messtechnik	(F M-FEINW M)	79
IEEE Transactions on Automatic Control	(IEEE AUTO C)	290
IEEE Transactions on Biomedical Engineering	(IEEE BIOMED)	85
IEEE Transactions on Industrial Electronics and Control Instrumentation	(IEEE IND EL)	103
IEEE Transactions on Instrumentation and Measurement	(IEEE INSTR)	61
IEEE Transactions on Reliability	(IEEE RELIAB)	124
IEEE Transactions on Vehicular Technology	(IEEE VEH T)	27
Instruments & Control Systems	(INSTR CONTR)	76
Instruments and Experimental Techniques	(INSTR EXP R)	189
Instrumentation and Control	(INSTR TECH)	62
International Journal of Control	(INT J CONTR)	159
ISA Transactions	(ISA TRANS)	56
Measurement and Control	(MEAS CONTRO)	59
Measurement Techniques USSR	(MEAS TECH R)	565
Medical & Biomedical Engineering	(MED BIO ENG)	133
Metrologia	(METROLOGIA)	26
Microtecnic	(MICROTECNIC)	17
NDT International	(NDT INT)	14
Non-Destructive Testing	(NON-DESTR T)	13
Proceeding Annual Reliability and Maintainability Symposium	(P AN REL M)	89
Review of Scientific Instruments	(REV SCI INS)	378
SIAM Journal of Control	(SIAM J CONT)	71
Technisches Messen ATM	(TEC MES ATM)	40

TABLE II
PART OF CITATION FREQUENCY MATRIX

CITED JOURNALS \ CITING JOURNALS	AUT REMOT R	AUTOMATICA	AUTOMATISME	IEEE AUTO C	INT J CONTR	SIAM J CONT
APPL SP REV	0	0	0	0	0	0
APPL SPECTR	0	0	0	0	0	0
ATM MESS PR	0	0	0	0	0	0
AUST J INST	0	0	0	0	0	0
AUT REMOT R	51	4	2	19	10	4
AUTOMATICA	4	43	0	86	56	7
AUTOMATISME	0	0	3	0	0	0
BIOMED ENG	0	0	0	0	0	0
CHEM INSTR	0	0	0	0	0	0
CONTR INSTR	0	0	0	0	0	0
CONTROL ENG	1	1	0	0	0	0
F M-FEINW M	0	0	0	0	0	0
IEEE AUTO C	19	61	0	626	204	47
IEEE BIOMED	1	0	0	2	0	0
IEEE IND EL	0	0	0	0	0	0
IEEE INSTR	0	0	0	0	0	0
IEEE RELIAB	0	0	0	1	0	0
IEEE VEH T	0	0	0	0	0	0
INSTR CONTR	0	1	0	0	0	0
INSTR EXP R	0	0	0	0	0	0
INSTR TECH	0	0	0	0	0	0
INT J CONTR	6	19	2	104	217	5
ISA TRANS	0	0	0	0	0	0
MEAS CONTRO	0	0	0	1	8	0
MEAS TECH R	0	0	0	0	0	0
MED BIO ENG	0	0	0	0	0	0
METROLOGIA	0	0	0	0	0	0
MICROTECNIC	0	0	0	0	0	0
NDT INT	0	0	0	0	0	0
NON-DESTR T	0	0	0	0	0	0
P AN REL M	0	0	0	0	0	0
REV SCI INS	0	0	0	0	1	0
SIAM J CONT	6	21	0	72	34	129
TEC MES ATM	0	0	0	0	0	0
total	553	394	69	1555	1001	559

citation frequency matrix is shown in Table II. Each row denotes a cited journal, with the last row being "total," whereas the columns are citing journals.

The procedure in the previous section is applied to the frequency matrix and the resulting diagram is shown in Fig. 1. The bold lines and the thin lines correspond to $(\alpha, \beta) = (0.05, 2.0)$ and $(\alpha, \beta) = (0.02, 2.0)$, respectively.

In Fig. 1 there are seven groups surrounded by dashed lines. These are the results of an agglomerative clustering based on a symmetrization of the frequency matrix. That is, the similarity matrix $S = (s_{ij})$ is derived as follows:

$$s_{ij} = \frac{\text{(frequency of mutual citations between } i \text{ and } j)}{\text{(frequency of total citations of } i \text{ and } j)} = \frac{t_{ij} + t_{ji}}{u_i + u_j}.$$

An agglomerative clustering based on the group average method [5] is applied and the dendrogram derived is shown in Fig. 2. We take seven groups at the similarity level 0.003. The

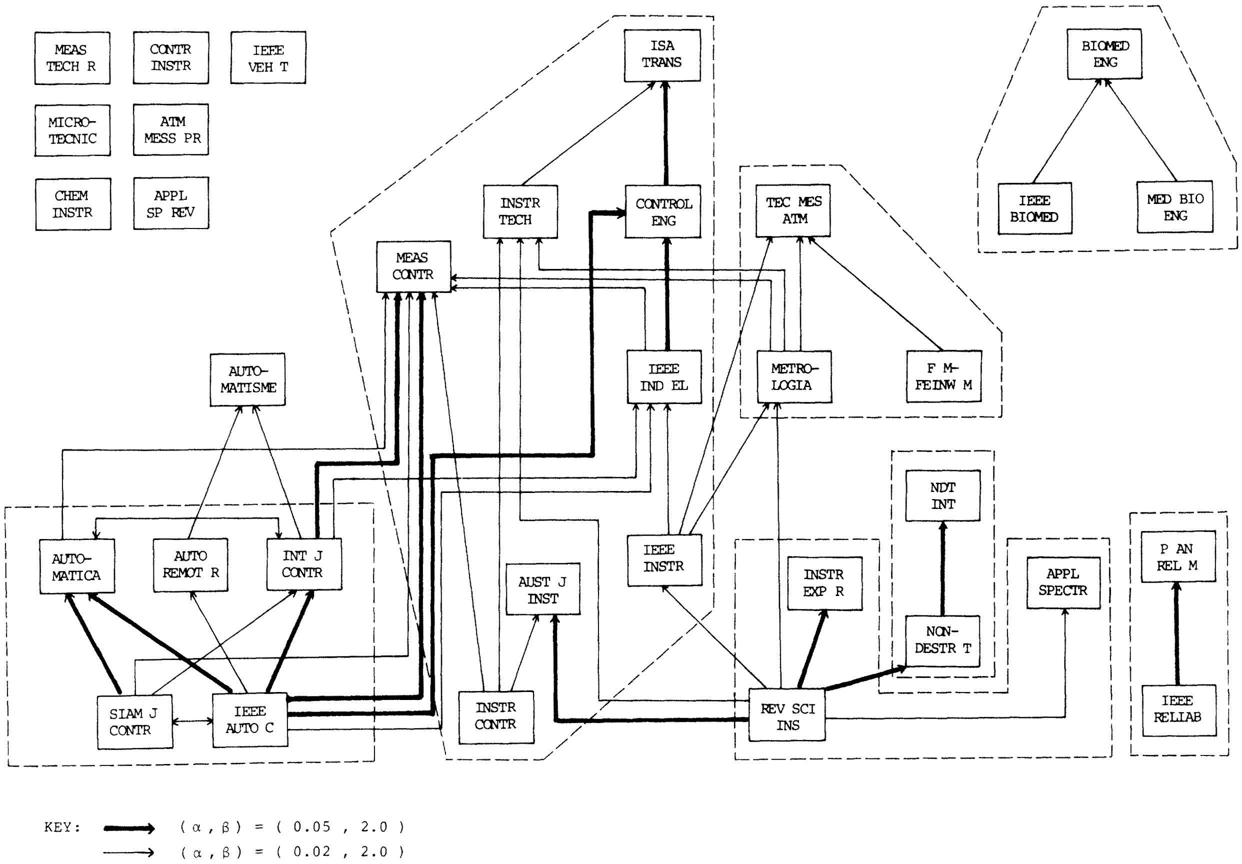

Fig. 1 Hierarchical diagram of journals in instrumentation/control engineering.

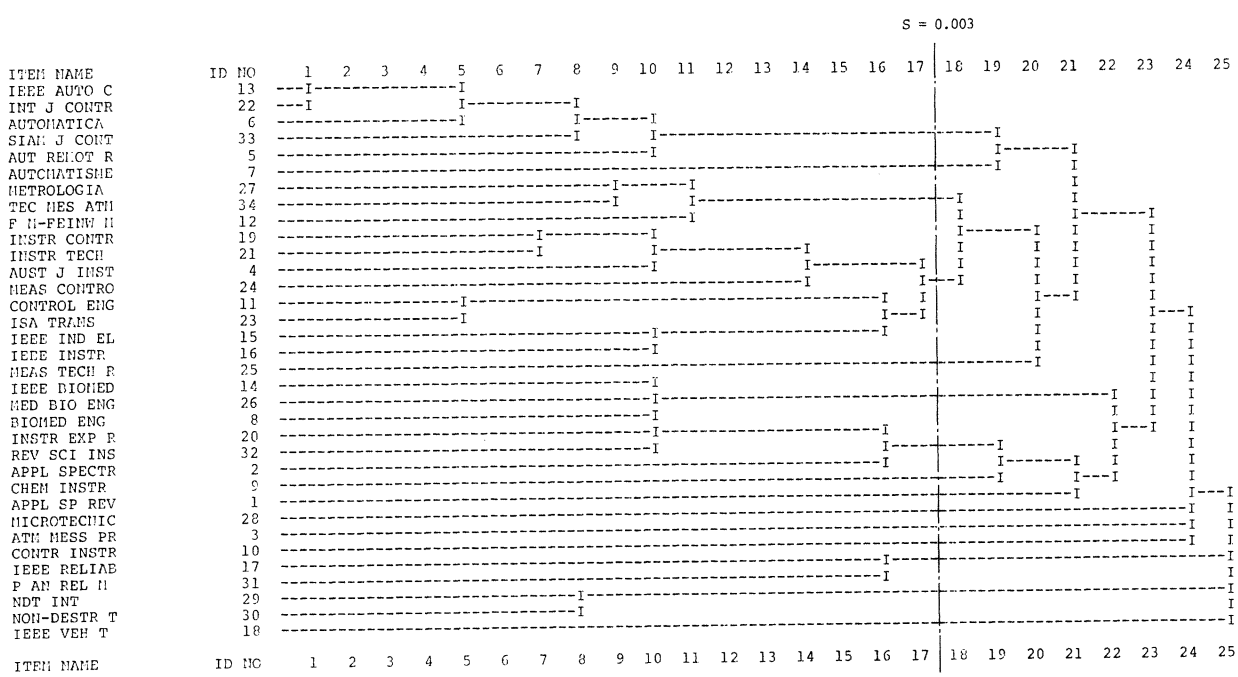

Fig. 2 Dendrogram derived by the group average method.

configuration of the graph is developed in two steps. In the first step, the diagram is generated automatically: the vertical positions are specified by the partial ordering described above; the horizontal positions are determined by the order of the elements in the dendrogram, i.e., IEEE AC is located at the leftmost side, whereas IEEE VEH T is at the rightmost side (cf. Fig. 2). Secondly, a manual rearrangement is performed so that the configuration becomes more compact.

Thus we obtained a figure showing two different types of information, that is, the nonsymmetrical dependences of scientific information between the journals by means of the hierarchical graph and the groups derived by a clustering procedure based on the similarity between the journals.

IV. Discussion

There seem to exist many variations of the method described above in order to deduce a directed graph for different purposes. However, our method has two distinct features: first, two thresholds are used to define the arcs; second, a normalization is performed before the thresholds are applied. For the second point, we have a reason to do it in our example of citation. Since some journals have thousands of citations and others have ten or twenty, we should have a graph concentrated on a few journals without the normalization.

The determination of the level (α,β) is not a theoretical but an empirical problem. However, the graph varies in a regular fashion with the change of the thresholds. For example, if $\alpha_1 > \alpha_2$, the corresponding $V(\alpha_1)$ and $V(\alpha_2)$ satisfy

$$V(\alpha_1) \subset V(\alpha_2).$$

Thus the decrease of α adds several arcs to the graph. The increase of α deletes some arcs from it. Therefore, if α is too small, the figure becomes very complicated. On the other hand, when α is too large, there may be a large number of isolated nodes. From the authors' experiences about journal citations, the value $\beta = 2.0$ gives satisfactory results, with α changing within $0.01 \leqslant \alpha \leqslant 0.10$ so that the figure is not too complex and at the same time there are not many isolated elements.

We can guess the meanings of seven groups in Fig. 1 derived by the clustering as follows. First, we see in the left side a group of five journals including IEEE AC and SIAM, which is clearly the "control theory" group. Next, there are three groups of instrumentation: (METROLOGIA, TEC MES ATM, F M-FEINW M), (REV SCI INS, INSTR EXP R, APPL SPECTR), and the largest group of eight journals. The first group is distinct because it contains two German journals; the difference between the second group and the last is more subtle. We guess the second group to have the inclination of physics (the central journal REV SCI INS is published by American Institute of Physics) and the last group contains that of engineering (it contains two IEEEs, Control Engineering, etc). The contents of the others are clear from the titles of the journals, i.e., there are biomedical engineering group, nondestructive testing, and reliability.

Journals that do not appear in any clusters have several characteristics, i.e., some have comparatively small numbers of total citation frequencies (ATM MESS PR, CONTR INSTR, MEAS TECH R, MICROTECHNIC, AUTOMATISME), some others have different inclinations from the others (CHEM INSTR, IEEE VEH T), and others have a large number of total citations but have weak relationships to any other element (APPL SP REV).

V. Concluding Remarks

The method described here is applicable in various disciplines of science and the expected results are as follows: 1) information that flows among scientific journals can be expressed by a directed graph and 2) subgroups are extracted by the clustering and show different inclinations in that discipline. This representation is useful in bibliographic management because it shows the relations among journals, their similarities, and influences among them.

Furthermore, other applications of this technique are possible. For example, it can be applied to the evaluation of an association test of educational psychology [8]. Thus, there is room for research of this method towards extending its areas of application.

Acknowledgment

The authors wish to express their deepest appreciation to Mr. S. Ueda of the University of Tsukuba for his helpful suggestions in preparing the manuscript.

References

[1] E. Garfield, "Historiographs, librarianship, and the history of science," in *Toward A Theory of Librarianship: Papers in Honor of Jesse Hauk Shera*, Conrad H. Rawski, Ed. Metuchen, NJ: Scarecraw, 1973, pp. 380–402.

[2] H. G. Small, "Co-citation in the scientific literature: a new measure of the relationship between two documents," *J. Amer. Soc. Inform. Sci.*, vol. 24, no. 4, 1973, pp. 265–269.

[3] ——, "Co-citation context analysis: The relationship between bibliometric structure and knowledge," in *Proc. 1979 Ann. Mtg. Amer. Soc.* Inform. Sci., pp. 270–275.

[4] F. Narin, G. Pinski, and H. H. Gee, "Structure of the biomedical literature," *J. Amer. Soc. Inform. Sci.*, vol. 27, no. 1, 1976, pp. 25–45.

[5] M. R. Anderberg, *Cluster Analysis for Applications.* New York: Academic, 1973.

[6] J. N. Warfield, "On arranging elements of a hierarchy in graphic form," *IEEE Trans. Syst., Man, Cybern.*, vol. SMC-3, no. 2, pp. 121–132, 1973.

[7] *Science Citation Index*, 1977 Annual, source index, Institute for Sci. Inform., Philadelphia, PA.

[8] Y. Higashibara, "Studies on scientific concepts formation—students' cognitive structure of physics concepts," Master's thesis, Univer. Tsukuba, 1979.

Use of Optical Reflectance Sensors in Robotics Applications

B. ESPIAU AND J. Y. CATROS

Abstract—**A new kind of proximity sensor with fiber optics and its use in some problems of robotics is considered. After modeling and simulation the sensors have been integrated into a gripper and used in some applications that are described. In the first part of this correspondence three data handling problems are presented. First, the problem of detection of targets is considered and various algorithms are compared; then, range estimation is performed using nonlinear filtering; and a third application is a simple problem of pattern recognition, solved using a two-sensor configuration. The second part of this correspondence is devoted to a control problem: the automatic grasping of moving objects, which requires real-time control of the manipulator with direct sensory feedback. In all cases experimental results are given.**

Introduction

It is well known that sensors are generally the critical point of many automatic systems. In particular the necessity of a good sensory feedback clearly appears in programmable automation, as mentioned by Rosen and Nitzan [14]. In the case of industrial robots, one of the main problems then is to get measurements from the end effector concerning its neighborhood. Conventional methods for designing intelligent robots require in this

Manuscript received March 30, 1979; revised September 24, 1980. This work was supported by the Delegation Generale a la Recherche Scientifique et Technique, under Grant number 77-7-0093 and IRIA, Grant numbers 76-102, 77-131, and 79-086.

The authors are with IRISA, Laboratoire d'Automatique, Campus de Beaulieu, 35042 Rennes Cedex, France.