A patent-based cartography of technology

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We use bibliometric (in particular patent-based) methods and techniques to develop a cartography of technology. Two types of maps are presented: *co-word* maps and *co-classification* maps. Both types of maps have been constructed for the entire domain of technology (the macro-level), i.e. the ensemble of all fields of technology in their mutual relations. Time series clearly illustrates the changing relations between the major clusters of technology, and in particular the changing role of fields which act as a "bridge" between clusters, or as a (declining or emerging) centre of technological activities within a specific cluster. Maps visualize relations between fields of technology. In order to have measures of the relative strength of these relations, we develop the concept of *affinity* between fields. A special feature of our macro-maps concerns the role of Japan in technology.

A second hierarchical level is the combination of several fields of technology (meso-level). As an example we constructed a co-word map for the emerging "crossroad" technology optomechatronics based on patents as well as on scientific publications. In this way, optomechatronics is mapped from a technological point of view, and from a research point of view.

The third hierarchical level concerns one specific field of technology (micro-level). Co-word maps have been constructed for the technology fields coating and crystal growing, optical equipment, and building materials.

An important aspect of the map is the possibility to identify centers of activity within a specifically defined field of technology. These centers of activity may indicate important innovative developments, or they may reflect important markets. Furthermore, we introduce the concept of "technological peripheries": for a specific technology field one may identify the direct "surroundings"; i.e. the most strongly linked fields.

Also, first attempts are made to map the "science and technology interface" by a specific combination of publication and patent data.

Our general conclusion is that the mapping methods and techniques presented in this publication already offer a unique way to visualize developments in fields of technology, and within technology as a whole. We emphasize that our technology maps are intended as a support tool, and never as a replacement of experts.

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1. Introduction

Technology constitutes a complicated, heterogeneous conglomerate of different fields of activity, characterized by many interrelated aspects. Undoubtedly, the interaction between fields of technology and between science and technology is often characterized by many feedback processes. Consequently, interactions will be of a "nonlinear" type. This is an important conclusion because nonlinearity may imply, as we know from recent developments in physics and mathematics [5] a chaotic, i.e. an unpredictable behaviour. Building on our earlier empirical findings concerning the fractal structure of scientific developments [18], we are currently investigating the role of nonlinear properties in science and technology as a self-organizing, "ecological" system [20,21]. Systematic investigation of this network of field interrelations, and with that, the overall structure of technology, is an important element of R&D management studies. Nowadays, the enormous and still increasing amount of information on technology, as embodied in, for example, patents, necessitates a systematic and careful approach to achieve data reduction. Large numbers of complex tables are mostly not very useful in this respect. They blur the overall structure underlying the whole of relationships represented in such tables. New and additional ways of representing the data may reveal these underlying and until then "hidden" features.

A fruitful approach to solve this problem is the development of maps. The advantages of using maps are multiple. First, a visualization of large and complex masses of data is much more easily grasped than tables. Second, they may offer a more complete overview in less time. Furthermore, visual information is more easily remembered. Another very important point is, as indicated above, the reduction of information. There is a lot of "noise" in the enormous amount of data available today. It is a crucial problem to filter the significant features. As we shall see, the mapping techniques developed in this study offer possibilities to achieve such a data reduction. In other words, a "cartography" of technology not only *reformats* the data into a specific graphical representation, they also accomplish *data reduction* while retaining the essential information. Hence, one may obtain an overview of relevant structures that is both sufficiently accurate and relatively easy to understand. The next step is obvious. Maps are not only suitable for depicting a static structure. A time series of maps enables a visualization of dynamic features of technology, for instance the identification of important changes over time in the development of technology fields, or shifts in R&D emphasis of countries and companies.

Maps of technology can be seen as relational indicators aimed at tracing, identifying, and analysing structures of technological activities as reflected by patents. In particular, they represent relationships between specific entities of information, such as inventors, companies, laboratories, countries, and so on. They may point at merging fields of technology, emerging new activities or "innovation centers", and they offer insight into the position of countries or companies in a technology field. Maps aggregate data from bibliometric sources (i.e. from written information products such as publications and patents) in a way no expert would be able to do. The cartographic approach is, so to say, independent of individual opinions. This is particularly advantageous in the case of broad and heterogeneous technology fields. Nevertheless, the advice of individual experts at various stages of the mapping process (e.g. in selecting keywords) can be very important.

Because maps offer such an "objectified" procedure for depicting relational features of technology fields, they thus introduce an alternative point of view as compared to the "subjective" view of experts. This does not mean that maps can replace the opinions of experts. On the contrary, a properly conducted and thorough interpretation of technology maps requires knowledge about the subject matter of the map, preferably from the "users" directly involved in the application of the maps. Therefore, the construction of maps requires a process of interaction between "map producers" and "customers" to determine possibilities and limitations of feasible types of maps.

2. Methods and techniques

2.1. Principal types of bibliometric maps

The advantage of the bibliometric (i.e. publication- and/or patent-based) method is the possibility to depict relationships between any combination of bibliometric information elements. Thus, a structure of related keywords, or of related references, or a structure generated by combinations of keywords and classification codes can be constructed. Each possibility refers to another aspect of the science and technology system and can be applied to different levels of aggregation (varying from R&D groups to entire companies, business sectors, or countries, or even entire fields of science and technology).

We here briefly summarize the main types of bibliometric maps relevant to our work. As bibliometric mapping has developed especially in science studies, we start with a short overview of science mapping (and thus mainly based on publications) and then proceed with the application of these methods in technology (by using patent data). A well-known type of map is based on co-citation analysis. These "co-citation maps" are based on the number of times two particular articles are *cited together* in other articles [14–16]. An interesting historical fact is that already in the 1960s first ideas about a technique closely related to co-citation analysis, called "bibliographic coupling" (which is in fact the "inverse" of co-citation analysis), were presented although published in rather unknown sources. References to this pioneering work [8] can be found, however, in Kuhn's famous *The Structure of Scientific Revolutions* [9, 2nd edn. 1970, p. 178).

When aggregated to larger sets of publications, co-citation maps indicate clusters of related scientific work (i.e. based on the same publications, as far as reflected by the cited literature). These clusters can often be identified as "research specialties". Their character may, however, be of different kind: because they are based on citation practices, they may reflect cognitive as well as social networks and relations. Several caveats are involved in this type of bibliometric mapping. To mention a few of the most important: citations only reflect a part of the intellectual structure, and they are subjected to a time lag.

So far, co-citation analysis has been applied to science fields. For technology fields, the same technique could be applied to patents. Here we have to analyse to which extent two particular patents are cited together in other patents. Although much pioneering work on citations in patents has been done by Narin and colleagues (see, for instance, Narin and Olivastro [10]), there is as yet no systematic exploration of technology fields by co-citation analysis. One of the problems is that the number of citations in patents is usually considerably lower than the number of citations in scientific publications. Another problem is the fact that if the cited patent is strongly related to the citing patent application, this would normally result in the rejection of the citing patent application. On the other hand, a very important advantage of citation-based techniques, and consequently also of co-citation analysis, is the implicit presence of a direction of influence: the distinction between cited and citing publications or patents unambiguously determines how the information flow is oriented.

A second type of bibliometric mapping is based on *word co-occurrences*. Word co-occurrences in a set of publications reflect the network of conceptual relations from the viewpoint of the scientists in the field concerned. These "co-word" frequencies are used to construct a "co-word map" which represents research themes in a field of science and their interrelations [1,2]. Co-word analysis is completely independent of citation practices. But it has, as always, its own problems. Main caveats are: words may have other than purely descriptive purposes and their meaning is often context-dependent. The main advantage of co-word analysis is given by the nature of words: words are the foremost carrier of scientific and technological concepts, their use is unavoidable and they cover an unlimited intellectual domain.

Instead of keywords, publications or patents can be characterized by *classification codes*. Thus, the co-occurrences of different classification codes enable a third type of bibliometric mapping: co-classification maps. Compared with words, classification codes have a well-defined and consistent meaning over the entire domain of analysis. Recent and extensive work on co-classification maps of science is done by Van Raan and Peters [19], and Tijssen [17]. Here the main restrictions are imposed by the specific nature of classification codes: they belong to a fixed classification scheme, and they might be out of date and subjected to biases in the indexing of the database. Furthermore, codes are assigned primarily for information retrieval purposes and do not necessarily reflect intellectual concepts. But the same nature also provides us the advantages of co-classification maps: their simplicity, enabling to explore main lines, and the possibility to use the structures given by the co-classification maps to evaluate the existing classification schemes.

This study specifically focuses on the exploration of co-word and co-classification analysis in technology by using the (co-) occurrences of keywords and classification codes in patents.

2.2. Patents as a source of data

During the last decade patent data have become more and more available through electronic databases. As a consequence, the interest in linking these patent data with other R&D related data and with economic data has increased strongly. The reason is quite obvious: like publications represent the state-of-the-art of science, patents reflect the current inventive and innovative developments in modern technology. However, for both types of documents similar restrictions apply: they will only partially describe the developments. Patents will never give a *perfect* indicator of industrial or governmental R&D activities. But they may offer an interesting monitor device to identify main lines and trends, and even, under specific conditions, the possibility to analyse R&D processes in more detail. Furthermore, applied research publications may reflect technological innovations in specific fields better than patents. In our earlier work [3] we amply discussed the problems involved in the construction of technology indicators based on patent data. We summarize the main problems that should be taken into account in any patent-based study [13]:

(1) How are patents linked to R&D activities, in particular what type of innovating activities are patented, and what are the differences between fields of technology with respect to the importance of R&D versus production engineering and design activities?
(2) What innovative activities result in patents and in which stage of the industrial innovation process does patenting occur?
(3) How do technology fields differ in propensity to patent, and does this propensity even within one specific field differ per country or per company?
(4) How are patent-based (output) indicators related with economic (market success) indicators?
(5) Now do patent-based findings compare to expert assessments, and are there typical characteristics in the (dis-) agreement between such quantitative and qualitative findings?

Despite these problems earlier results of patent analysis have proved useful. Careful and thorough studies do provide relevant empirical data in order to sharpen research questions and to enable a more fruitful approach to the construction of applicable technology indicators. The reason for this is simply that patents contain a wealth of data on R&D activities. Again, it is of crucial

Table 1
Table of technology fields, with code and delineation by IPC symbols

Code	Technology Field	IPC symbols
BA	Mining, civil engin., airconditioning, Building materials, waste disposal	A47 (not J, L), A62, B09, B24, C02, C04, E01–21, F24, F25D, F23 (not R)
PP	Paper, printing	B31, B41–44, D21
TE	Textiles, apparel, leisure, textile mach.	A41–46, A63, B68, C14, D01–07
ME	Biomedical engin. (biomedicine)	A61 (not K)
NA	Agricult., nutrition, beverages, tobacco	A01–24, C08B, C12C,G,H,J,L, C13
GP	Bio- and genetic engin. (genetics), pharmacy	A61K, C07G,H,J,K, C122F,M,N,P,Q,R
OC	Organic chemistry, petrochemistry	C07B,C,D,F, C10, C11
PC	Polymer materials (polymer chem.)	C08C,F,G,H,L
SY	Manufact. & appl. of polymers (Synthetic resins, paints, etc.)	B29, C08J, K, C09
IC	Inorganic chemistry, glass, explosives	C01, C03, C05, C06, F42
CO	Coating, crystal growing	C23, C25, C30
SM	Process engin., separation, mixing	B01–08, B32, F25C, J, F26
MA	Mech. engineering, mach., armament	F15–17, F27, F41
MM	Material processing, machine tools	B21–24, B25 (not J), B26–27, B30, C21–22
HA	Handling, conveyor equipm., robots	B25J, B65–67
TR	Transport, traffic	B60–64
ET	Engines, turbines, pumpes	F01–04, F22, F23R, F25B, FZ8
EN	Electric power, nuclear technology	G21, H02B,G,H,J,M, H05H
EM	Electrical machinery	A47L,J, H01B,C,F,G,H J K M R T, H02K,N,P, H05B,C,F,G
LA	Lasers	H01S
OP	Optical equipment	G02, G03
IN	Instruments, controls	G05, G07–10, G12
MS	Metrology, sensors	G01, G04
DA	Data processing	G06
IS	Information storage	G11
TC	Telecomm. (not image transmission)	H01P,Q, H03, H04 (not N)
IM	Image transmission	H04N
EL	Electronics, electronic components	H0IL, H05K

importance to proceed carefully. For instance, when using patents as a data source, one must take into account that national patent offices provide data that are strongly biased and specific patenting cultures toward inventions of minor importance: the so-called home advantage. Furthermore, patenting "behaviour" and tradition are very much culturally influenced. This is especially the case for Japan. The problems of home advantage biases and specific patenting cultures can be avoided to a large extent by focusing on *international* patenting activities. Here the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO) are of crucial importance.

In our foregoing study [3] we constructed technological activity indicators using patent data from these two patent offices. Here we report on the use of patent data for the "mapping" (cartography) of technology.

We aggregated the patent data (using the databases EPAT and WPI/L) into 28 fields of technology, following the work of Grupp and Schmoch [7]. These fields are defined with the help of International Patent Classification (IPC) codes. They cover the entire domain of technology, and are differentiated to emphasize recent high-tech developments. Therefore, "traditional" fields (such as inorganic chemistry or building technology) tend to be larger in size (in terms of number of patents) than the more "modern" fields (such as genetics and electronics). Table 1 lists these 28 fields of technology with code (abbreviation), description, and IPC codes. For a more detailed discussion we refer to Engelsman and Van Raan [3]; see also Grupp [6, pp. 348–352].

2.3. *The construction of maps of technology*

In section 2.1 we discussed the general methodological principles of mapping of science and technology based on the co-occurrence of specific information elements (e.g. citations, keywords, classification codes) in publications or in patents. Here we focus on the specific techniques applied in this work.

We used co-classification analysis for maps of the *entire domain* of technology, i.e. the ensemble of all 28 fields (as discussed in section 2.2) in their mutual relations. Thus, co-classification analysis is the basis of our "macro-maps". Co-word analysis has been applied primarily to visualize the (internal) structures of combinations of related fields of technology (meso-maps) and of individual fields (micro-maps). We also applied co-word analysis for the entire domain of technology (macro-map) in order to compare the structures based on co-classification with those based on co-word analysis.

With the following concrete example we present the more technical details of co-word and co-classification analysis. For the macro-map based on co-word analysis we collected for priority year 1987 all indexed keywords in patent titles and patent abstracts for each of the 28 technology fields (using the database WPI/L). Thus, a table is composed comparable to table 1, but now in the third column a set of keywords instead of IPC codes. In this way, each field of technology is characterized by a specific set of keywords. The 28 keyword sets form together a total set of keywords. For the 28 fields we counted – field by field – the number of patents characterized by each of the keywords in the total set. Thus we constructed a matrix of keywords versus technology fields, consisting of the "wordprofiles" of fields as matrix columns. Matrix rows are indicated by parameter i, matrix columns by parameter j. Correlating these wordprofiles (or matrix columns) results in a correlation matrix (fields versus fields). The value in the cells $\{c_{ij}\}$ of this new "co-field" matrix is the correlation measure between field i and field j based on their common wordprofile (a basic mathematical discussion is given in Engelsman and Van Raan, [4]).

The newly created co-field matrix gives us the relational strengths between all the 28 fields one with another, and this relational structure can be displayed in two-dimensional space by multidimensional scaling, thus yielding a map in which positions of technology fields are indicated, based on word relations. Therefore, in this macro-map *fields* are displayed according to their mutual relations.

In the case of co-word analysis on the meso-level (a combination of several fields) and on the micro-level (one specific field) we used only the set of keywords of the field or combination of fields concerned (for practical reasons, a threshold for the maximum number of keywords per contributing set must be fixed). For each of the keywords we analysed the co-occurrence with any other keyword in the set, i.e. we counted the number of patents in a specific field or field combination having any possible pair of keywords. This co-word matrix is also displayed in two-dimensional space, but now *keywords* are positioned in the map according to their mutual relations.

The above sketched process of online patent data collection, construction of co-word matrices, and multivariate techniques to produce the maps, is highly automated. This enables us to produce maps of technology in a reasonably economic way.

In the next section we present a co-word map of the entire domain of technology for the priority year 1987 (macro-level); at the meso-level a map of the "crossroad" technology opto-mechatronics (i.e. the integration of optical, mechanical, and electronical developments), defined as a combination of the fields HA (handling, conveyor equipment, robots), MS (metrology, sensors), and OP (optical equipment), for the priority year 1987; and at the micro-level maps of one of the abovementioned constituent fields (OP) separately, and, furthermore, of the fields CO (coating, crystal growing) and BA (building materials, mining, civil engineering, etc.), again for the priority year 1987.

For the co-classification analysis we proceeded in a similar way as described in the discussion of the co-word analysis. In this case, however, the resulting co-field matrix is based on co-occurrences of groups of IPC codes. Again this results in a macro-map of the entire domain of technology, representing mutual positions of all fields of technology, but now based on IPC code relations. Such a map is important as all new patented technological developments are classified in terms of IPC codes.

In this publication we present co-classification-based maps (or "co-IPC" maps) for the entire domain of technology (mutual relations of all 28 fields of technology) for the priority years 1979/1980 and 1987/1988. In addition to these maps, we can also use the above discussed co-field matrix for an alternative calculation of the relations between fields of technology. For example, let us consider in the co-field matrix *column j* for field CO (coating, crystal growing). The diagonal element [cy $\{c_{jj}\}$ in this column contains the total number of CO (-related) patents. If we now consider another field as a matrix *row i*, say BA (building materials, mining, civil engineering, etc.), then the crossing of this BA-row (i) with the CO-column (j) corresponds with matrix cell $\{c_{ij}\}$, indicating the number of co-occurrences of these two fields in patent classifications. We define the ratio c_{ij}/c_{jj} as the "affinity" of CO with BA, whereas in a similar way the ratio c_{ij}/c_{ii} can be seen as the "affinity" of BA with CO. These mutual affinities can be presented in a comprehensive way, as will be discussed in the next section.

The connections between the above maps are indicated in fig. 1. The (co-classification) macro-maps give a picture of the structure of the entire technology domain. We present these macro-pictures for two periods: 1979/1980 and 1987/1988. Furthermore, for each of these two periods we present four modalities: one based on European patents; a second on patents worldwide; a third on patents worldwide but without Japan; and a fourth based solely on Japanese (national) patents.

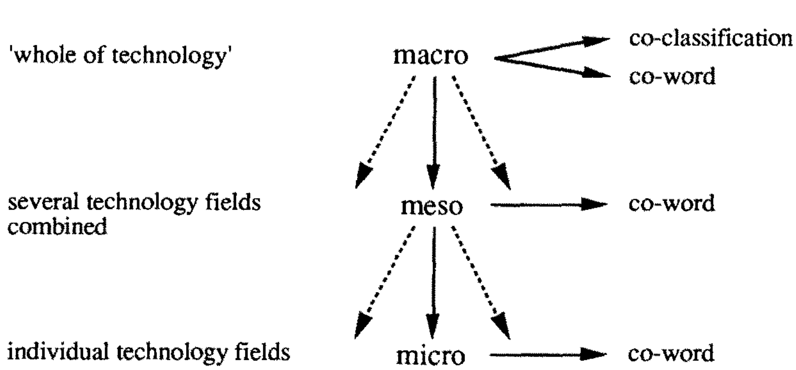


Fig. 1. Hierarchical levels of the different mapping approaches.

As a methodological exercise, one co-word-based macro-map has been constructed for the year 1987. It is clear that the above discussed macro-maps represent the highest hierarchical level ("the whole of technology"). Looking at a lower hierarchical level, we may consider meso- and micro-maps as a "zoom" into some of parts of the macro-map. This zoom makes it possible to observe the details of specific field combinations (meso-level) or of individual fields (micro-level), which would otherwise remain invisible in the macro-map of the whole of technology.

These meso- and micro-maps are based on a co-word technique, in order to put directly the concepts of importance on the map. As yet, these maps have been constructed for the priority year 1987 only.

3. Results and discussion

3.1. Maps of technology on a macro-scale

Some introductory remarks

Before the maps are presented, some remarks on how to read the maps are necessary. The applied mapping technique (multidimensional scaling) in principle puts fields with strong resemblance close together. Since we use only two dimensions for our representation, this positioning is not always perfect. In fact, this positioning is based on global resemblance (profile similarity) of the information elements concerned. To include the information on pair relations (word–word, or field–field) as available in the co-occurrence matrix, a numerical value for these mutual

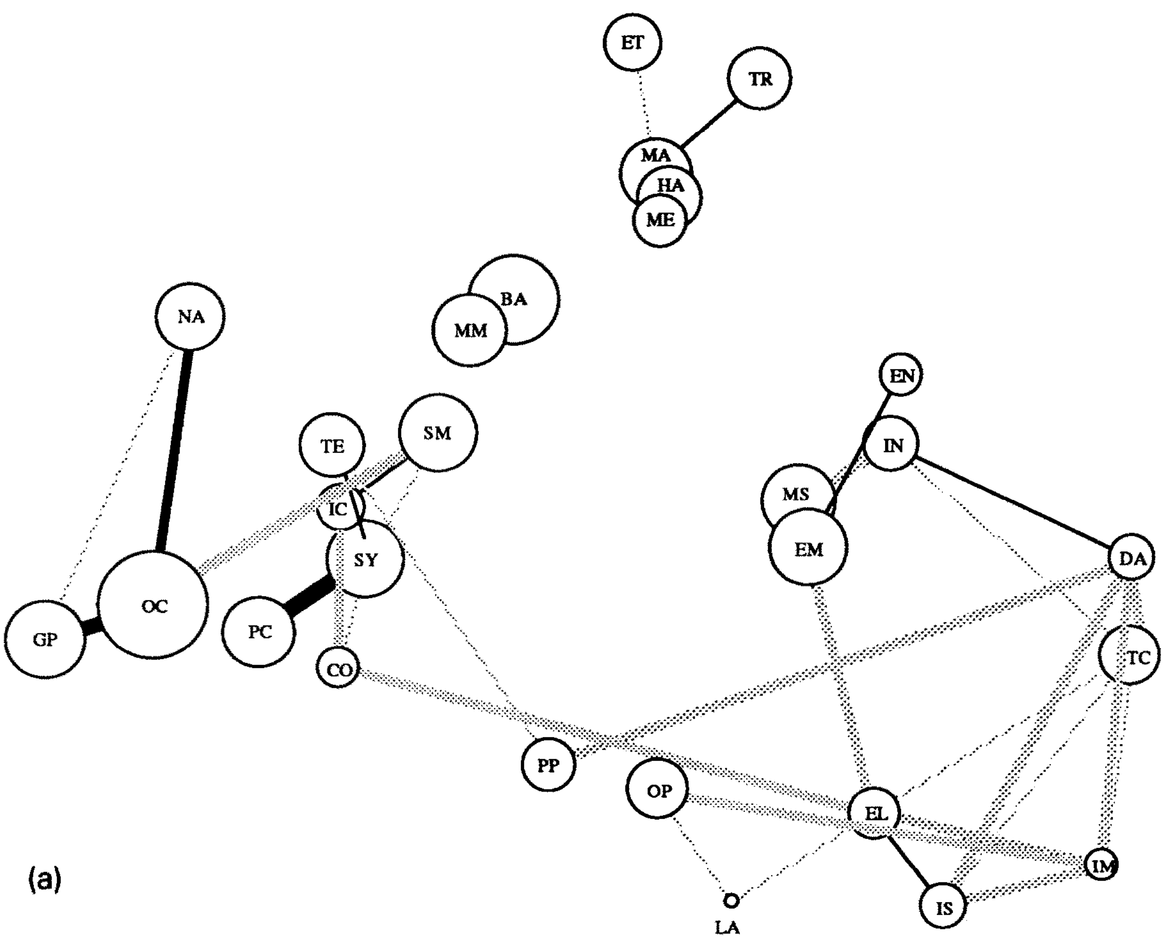


Fig. 2(a). Co-classification (co-IPC) map for EPO patents, database EPAT (1979/1980). Surface of the circles is proportional to the size, in terms of number of patents, of the fields. The two-letter abbreviation corresponds to the name of the field as indicated in table 1. (b) Co-classification (co-IPC) map for EPO patents, database EPAT (1987/1988).

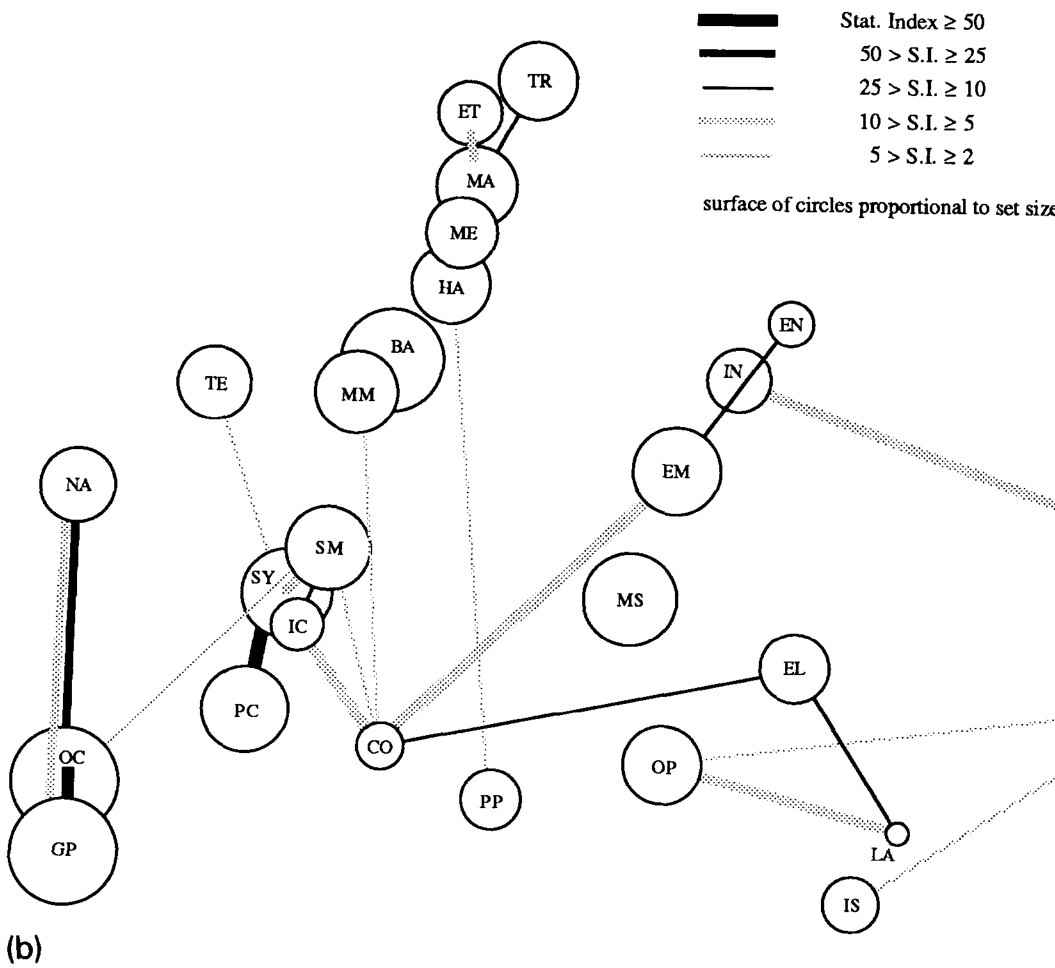


Fig. 2 (continued).

relations was established, using the statistical index (a mathematical formulation of this index is given in Engelsman and van Raan [4]). These strengths are indicated by connecting lines, the thickest line representing the strongest relation.

A macro-view of "Europe"

In fig. 2(a) we present the co-classification map based on EPO patents (data extracted from the database EPAT) for the years 1979/1980. As we mentioned before, this co-classification mapping pertains to the entire domain of technology, i.e. to all 28 fields of technology together (macro-map). We emphasize that the x- and y-axis do not necessarily represent specific parameters. The structure itself is essential.

The first striking detail of the map is a clustering of the technology fields into three main areas: chemical technology, mechanical technology, and electronics. Furthermore, one immediately notices the connection of the chemistry cluster with the electronics cluster through the field CO (coating, crystal growing), while the mechanics cluster remains more or less isolated.

The next step is to compare these findings with the more recent map of 1987/1988 (fig. 2(b), again based on EPO patents, extracted from EPAT) in order to find temporal ("longitudinal") changes. On the whole, the same structure can be observed. Nevertheless, there are some interesting changes. In the 1987/1988 map the chemistry and mechanics clusters seem to be aligning along some imaginary axis, running from GP (genetics, pharmacy) at one end, to TR (transport, traffic) at the other end. We shall come back to this point later. Looking into more detail, one observes a recent relation between PP (paper, printing) and HA (handling, conveyor equipment, robots), and also between EM (electrical machinery) and CO (coating, crystal growing). LA (lasers) has become less an outer province of technology. The electronics cluster seems to fall apart into two main subclusters: one with EM (electrical machinery), EN (electric power, nuclear technology), and IN (instruments, controls) connected with DA (data processing) and TC (telecommunication); and another one with EL (electronics, electronic components), OP (optical equipment), LA (lasers), IS (information storage), and IM (image transmission). Furthermore, a striking feature is the increasingly stronger role of CO (coating, crystal growing) as a bridge between all three main clusters. In how far we can speak of a real bridge in the case of CO, i.e. in the sense that CO is functioning as a transfer point for technological knowledge flowing from one cluster or field to another, or that in fact CO is very much an interdisciplinary field in which technological knowledge from other different fields is being applied, remains to be clarified.

Continuing with our longitudinal analysis, we observe in the series of EPAT maps the changing role of laser technology. Very clearly, LA (lasers) is in the recent period much less an outer province in technology than about a decade ago. In particular, LA nowadays shows important relations with

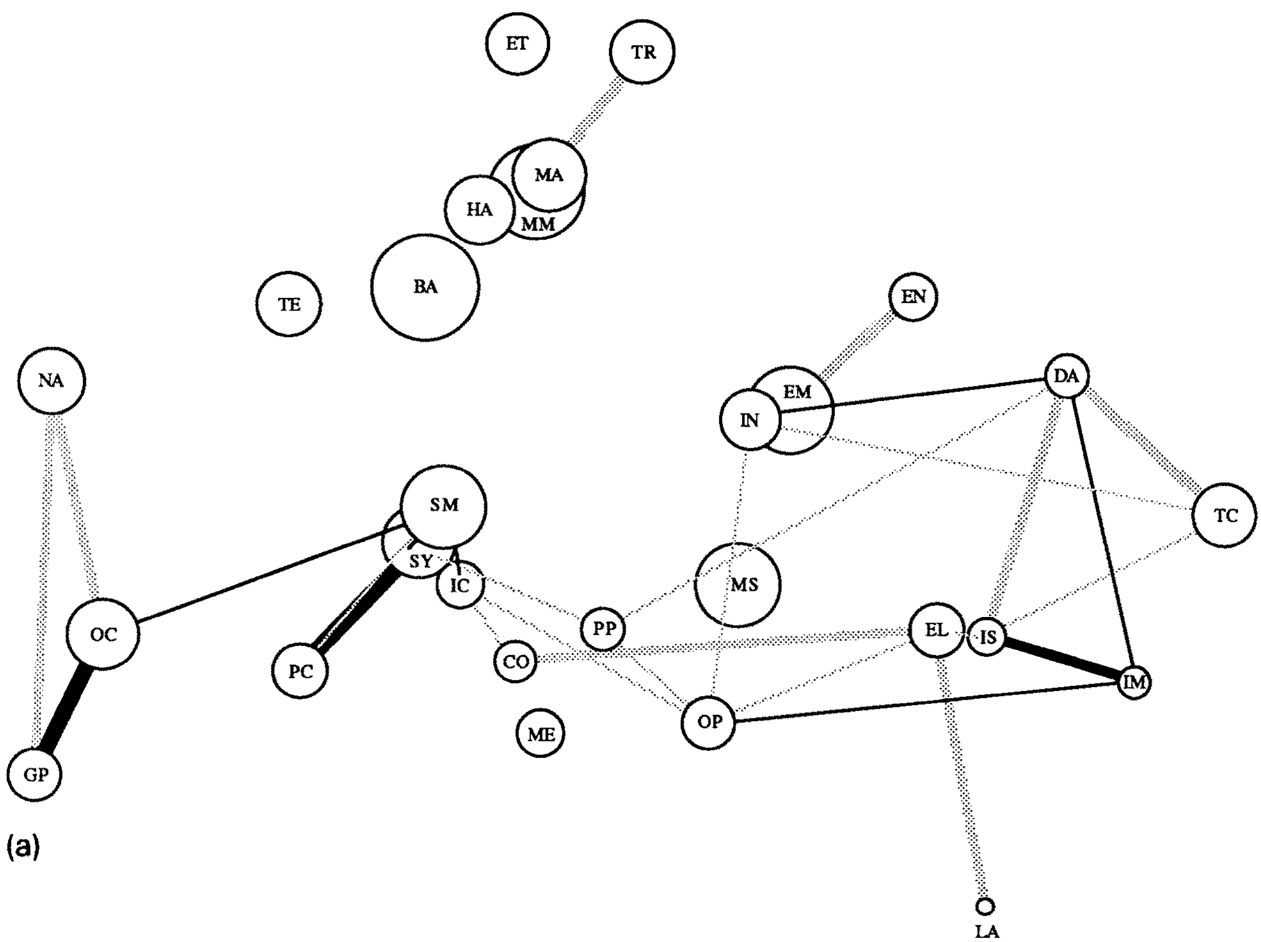


Fig. 3(a). Co-classification (co-IPC) map for patents worldwide, database WPI/L (1979/1980). (Legend see fig. 4(b).) (b) Co-classification (co-IPC) map for patents worldwide, database WPI/L (1987/1988). (Legend see fig. 4(b).)

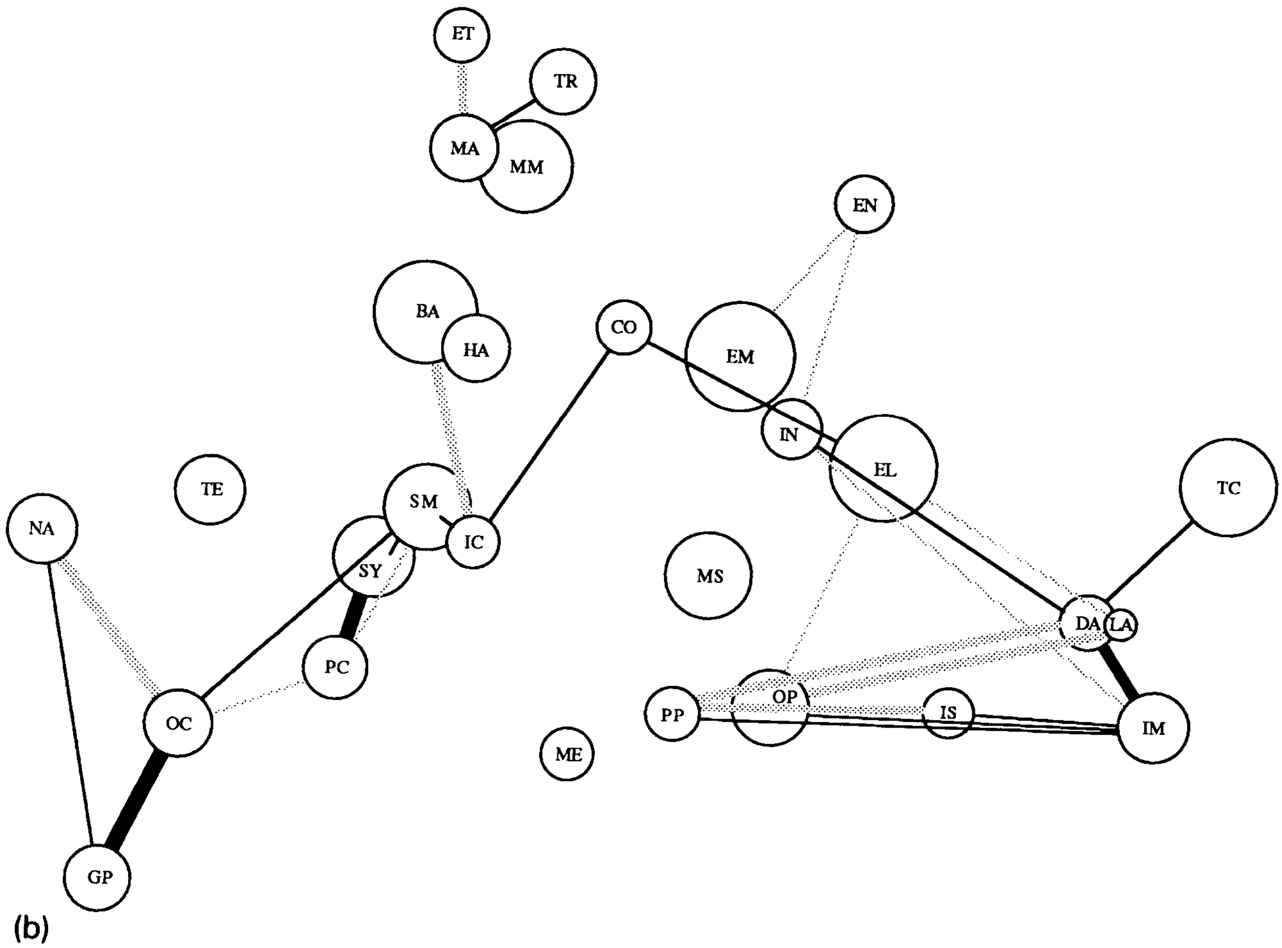


Fig. 3 (continued).

OP (optical equipment) and EL (electronics, electronic components). Furthermore, we observe central positions of OC (organic chemistry, petrochemistry), SM (process engineering, separation, mixing), IC (inorganic chemistry), CO (coating, crystal growing), SY (manufacturing and application of polymers), MA (mechanical engineering, machinery), EM (electrical machinery), and EL (electronics, electronic components). We observe a closer relation between the mechanical and the electronical technology clusters in general, and a particular "bridge" between HA (handling, conveyor equipment, robots) and PP (paper, printing). We already mentioned the central role of CO (coating, crystal growing), and this field of technology strengthened its position as a "bridge" between all three main clusters, the chemistry, the mechanics and the electronics cluster. In the chemistry cluster, we see in recent times a closer relation between GP and NA (forming together with OC a biochemistry subcluster), somewhat isolated from the SY, PC, SM, and IC (process engineering/polymer) subcluster.

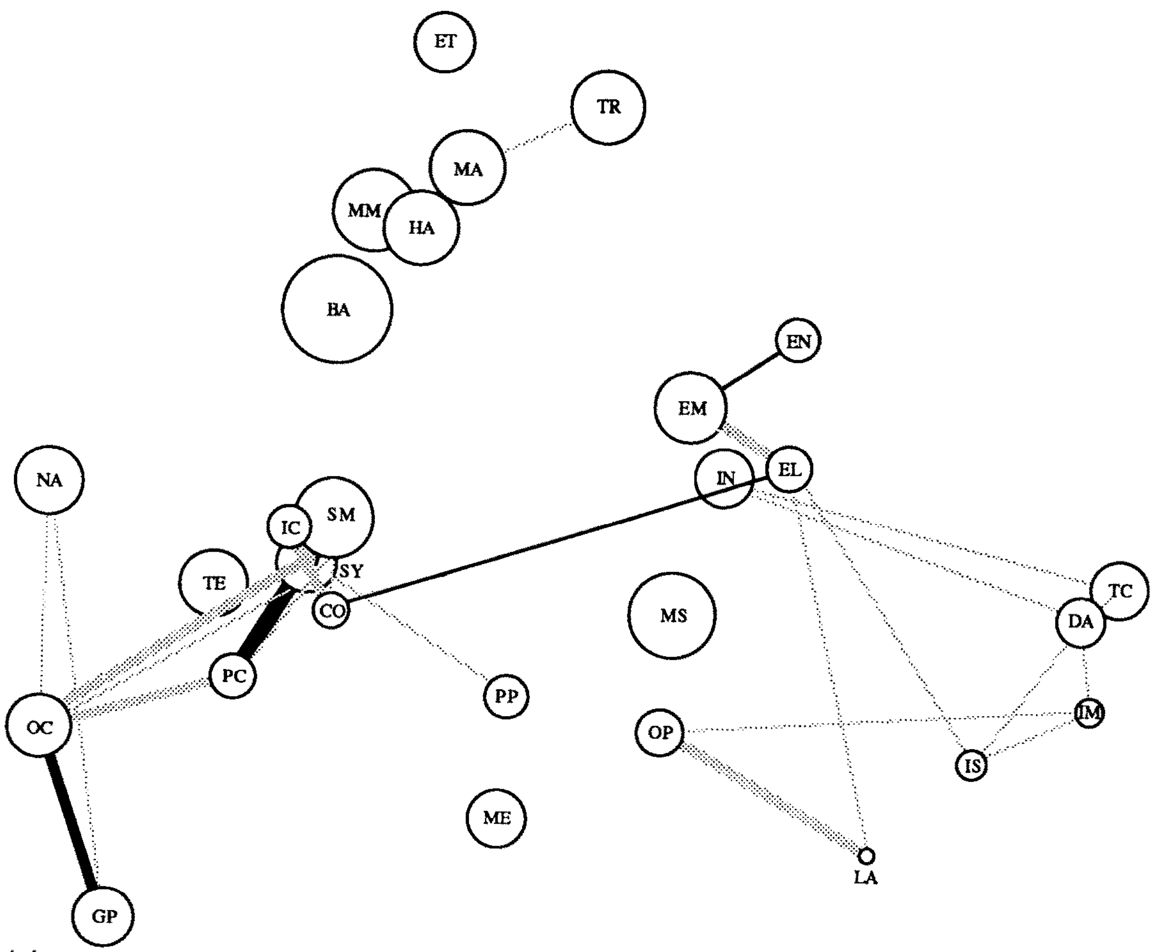
We remark that in our maps the stronger linkages are emphasized by connection lines. So if we observe that EM (electric machinery) was linked to EL (electronics, electronic components) in 1979/1980 (fig. 2(a)) whereas this linkage has "disappeared" in 1987/1988 (fig. 2(b)), we conclude that both fields are still linked (they are clearly in each others "vicinity" on the map!) but the particular link between EL and EM decreased in strength compared to the relations of EL with (many) other fields. Similar arguments apply to the linkage between IS (information storage) and OP (optical equipment).

A macro-view of the "world"

A similar comparison can be made with the maps based on nearly worldwide patents (i.e. patents of 30 industrialized countries, extracted from WPI/L). In the map for 1979/1980 (fig. 3(a)) again we see the three main clusters, although within the chemistry cluster we observe very clearly two subclusters: one with SM (process engineering, separation, mixing), SY (manufacturing and application of polymers), IC (inorganic chemistry), and PC (polymer materials); and another one more biochemical in character, with GP (genetics, pharmacy), NA (agriculture, nutrition), and OC (organic chemistry, petrochemistry). But we notice the same "bridge" between the chemistry and the electronics clusters: the technology field CO, this time accompanied by the technology field PP (paper, printing).

The worldwide map for 1987/1988 (fig. 3(b)) shows, just like the corresponding EPAT (European patents) map, how the large mechanics cluster, after having been isolated (1979/1980), in recent times has moved to the chemistry cluster. Striking are also the strong relations between IM (image transmission), IS (information storage), DA (data processing), OP (optical equipment), LA (lasers), PP (paper, printing), and TC (telecommunication), in contrast with the EPAT map of 1987/1988.

A plausible explanation of this is the dominating role of national patents from Japan (domestic and foreign patents, i.e. all patents with the first



(a)

Fig. 4(a). Co-classification (co-IPC) map for patents worldwide without Japanese, database WPI/L (1987/1988). (Legend see fig. 4(b).) (b) Co-classification (co-IPC) map for Japanese national patents, database WPI/L (1987/1988).

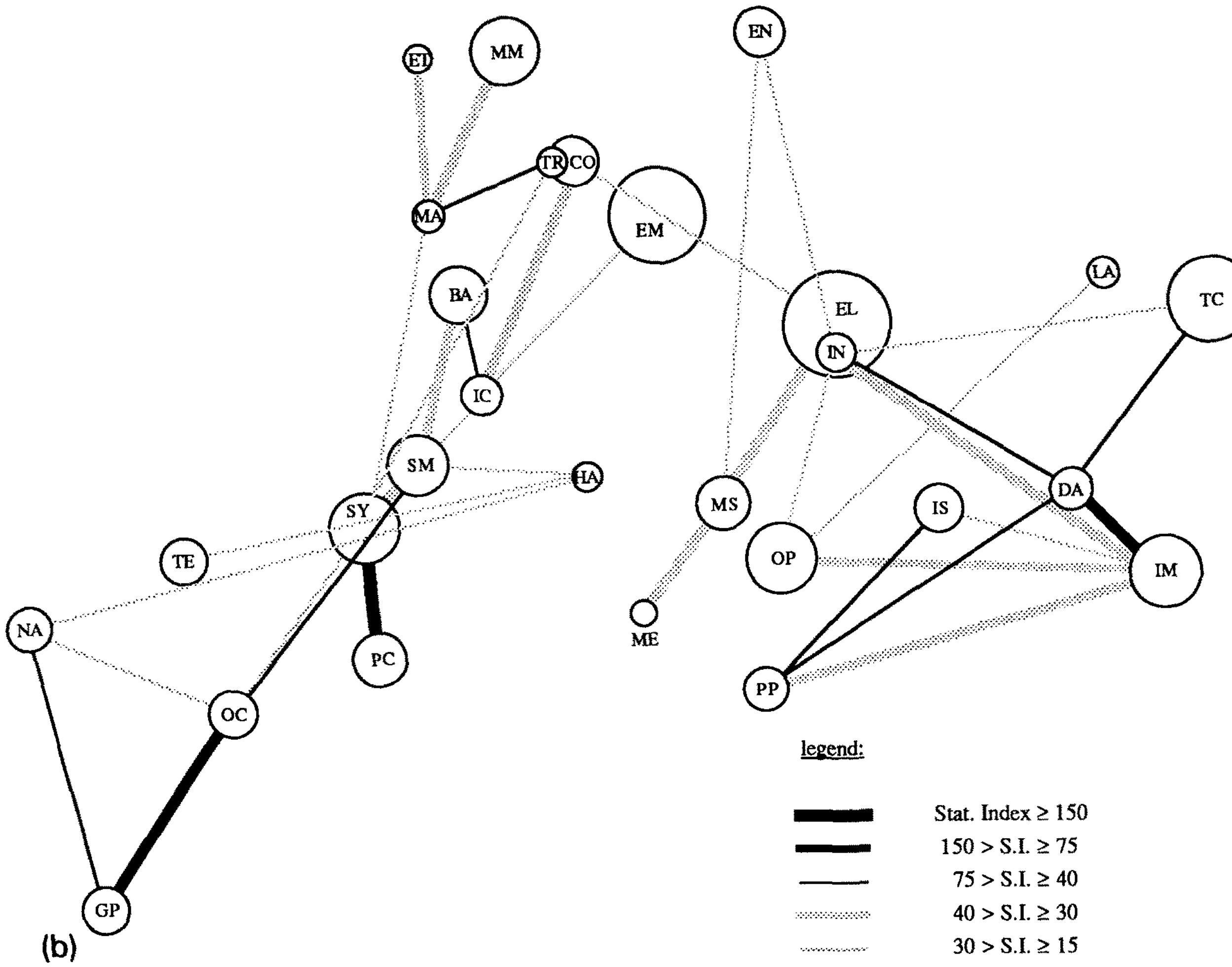


Fig. 4 (continued).

priority being Japanese) in the WPI/L database. Because of the domestic patenting behaviour in Japan, fields of strong Japanese activity (which is indeed the case for most of the above fields) are over-represented in the database, and therefore the relations between these fields will be biased. In fact, half of the number of patents in the database WPI/L with the priority year 1987/1988 consists of patents with Japanese priority. To corroborate this conjecture, we removed from the WPI/L data all national patents from Japan, see fig. 4(a). Additionally, we performed the complementary exercise: a WPI/L-based map (1987/1988) with only national patents from Japan, see fig. 4(b). We indeed observe that the strong IM-IS-DA-OP-TC network is clearly based upon patenting activities in Japan. Furthermore, one can see that the more "modern" (and electronics-related) fields (EL, TC, IM, OP) are larger in size than the more "classic" (and mechanics-related) fields (BA, MA, HA, TR, ET) and the chemistry fields (the size in the map reflecting the number of patents in the respective field). All of this reflects the preference of Japanese patenting behaviour as studied in our foregoing publication. Undoubtedly, patent data from Japan are necessary to get a realistic picture of relations between fields of technology, but in our opinion these patents should be limited to foreign Japanese patents, i.e. patents of Japanese inventions, applied for at a major foreign patent office such as USPTO or EPO. In other words, we have to "remove" the national patents from Japan. Therefore, we conclude that a more realistic picture of the overall relations between these fields is given by the EPAT map (no maps based on USPTO patents are available as yet).

Returning to the comparison of the 1979/1980 and 1987/1988 WPI/L maps (figs. 3(a) and 3(b), respectively), we see roughly the same picture as the one that emerges from the EPAT maps. However, there are also remarkable differences, mainly due to the above mentioned Japanese "overactivity" in patenting. In the chemistry cluster we see a stronger relation between the biochemistry subcluster (GP, OC, NA) and the process-engineering/polymer subcluster (SM, IC, SY, PC) than in the EPAT maps, mainly because OC (organic chemistry, petrochemistry) acts as a "bridge" between both subclusters. We already mentioned the much stronger (than in the EPAT case) interrelation between a number of fields, with DA (data processing) playing a very central role: IS (information storage), OP (optical equipment), PP (paper, printing), IM (image transmission), LA (lasers), EL (electronics, electronic components), IN (instruments, controls), TC (telecommunication) and IM (image transmission). Other remarkable observations are the (emerging) relation between BA (mining, civil engineering, building materials, etc.) and IC (inorganic chemistry), which in fact splits the "old" mechanics cluster into two subclusters, and the position of ME (biomedical engineering): in the EPAT 1987/1988 map in the mechanics cluster, but in the WPI/L 1987/1988 map much closer to the electronics cluster.

A closer look at Japan

Comparing fig. 4(a) ("world without Japan") with fig. 4(b) ("only Japan"), we find indeed that most of the striking features discussed above are in fact characteristics of Japanese technology: the strong relation between OC (organic chemistry, petrochemistry) and SM (process engineering, separation, mixing); the relation between BA (mining, civil engineering, building materials, etc.) and IC (inorganic chemistry); the remarkably central role of DA (data processing); and the position of ME (biomedical engineering). As far as this latter field concerns, we observe that nowadays it is connected with the electronics cluster mainly through its relation with the MS (metrology, sensors). A striking feature of the Japanese map (fig. 4(b)) is the position of CO (coating, crystal growing): it is positioned close toward the mechanics cluster. The main reason for this is that major parts of Japanese chemical and electrical/electronic technology are more closely (as compared to the European and worldwide maps) related to the mechanical sector. In particular, electrical machinery (EM) carries CO along.

It is tempting to compare the position of technology fields on this map with the figures for the Japanese technological preference as presented in our earlier work [3]. However, we must remark that any such comparison must be taken with care since we are comparing (1) patent data from WPI/L (as far as the map is concerned) with patent data from EPAT (for the technological preference), and (2) national patents (Japanese priority) with patents having Japan as inventor country.

Taking this in mind, we here list some first observations. We already mentioned the connection of ME (biomedical engineering) with the electronics cluster. In our foregoing publication we showed that ME is a field of increasing Japanese preference starting from a very low level of (relative) activity [3, pp. 41]. Furthermore, we remark that most of the fields that have a central position on our map (fig. 4) are also fields of a strong to very strong, or at least an increasing Japanese preference. For instance: MA (mechanical engineering, machinery), SM (process engineering, separation, mixing), EL (electronics, electronic components), IN (instruments, controls), DA (data processing), PP (paper, printing), SY (manufacturing and application of polymers), IS (information storage), IM (image transmission). There is one exception: BA (mining, civil engineering, building materials, etc.) shows a central role ("bridge" between the chemistry and the mechanics cluster), but the Japanese preference is still low for this field. A further striking feature of the Japanese map is the rather isolated position of HA (handling, conveyor equipment, robots). Indeed, we found a very low and even decreasing Japanese preference (at least in the European patent system) for this field [3, p. 41].

Another macro-view of the world

The above concerns the findings with macro-maps based on co-classification analysis. As discussed in section 2.3, we also constructed a macro-map based on co-word analysis. Data collection for a co-word macro-map is much more laborious than for co-classification macro-maps. Therefore, we present in this publication as a first exercise (only distances, no linkages strengths indicated) the co-word macro-map for 1987 (see fig. 5). The map is based on about 10 000 keywords in EPO patents extracted from database WPI/L.

Inspection of this co-word macro-map yields the following impression. The main features of the corresponding co-classification maps are again visible: areas of clustered chemical, mechanical and electronical fields. We also observe that the mutual positions of these three main clusters of technology show a remarkable similarity with the co-classification maps (although the chemical and mechanical fields seem to be more "aligned"). Clearly, patent classification codes and keywords converge as far as the coarse structure of technology is concerned. This is an important empirical finding, as both types of information elements are largely independent of each other. We verified this statement by comparing for some arbitrarely chosen (sub)fields of technology the words involved in the classification code (IPC) description with the (most frequent) keywords from the patents in these fields. It is therefore tempting to state that our maps actually yield *a* (but of course not necessarily *the*) "real" structure of technol-

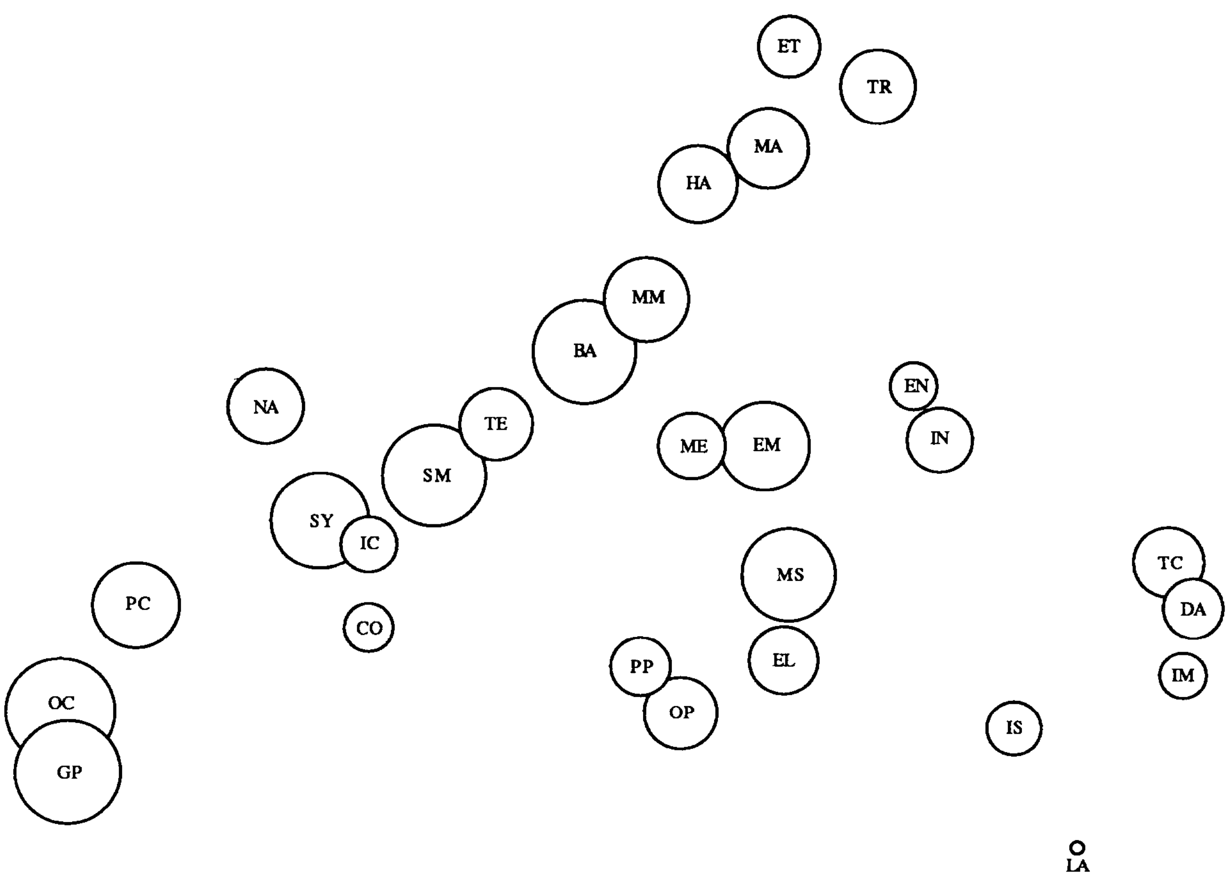


Fig. 5. Co-word map, based on indexed keywords, for EPO patents, database WPI/L (1987). (Legend, surface of circles proportional to set size.)

ogy, i.e. a structure having a meaningful texture (e.g. mutual distances, dimensions).

As we mentioned before, we notice a remarkable axis-like structure. The chemistry and mechanics clusters are on one axis, while the electronics cluster is spread out over a perpendicular axis. The imaginary origin of this coordinate system is somewhere near the field HA (handling, conveyor equipment, robots). Such axis-like structures often indicate specific "dimensions"; representing a particular main characteristic of the global system. A remarkable finding is the position of the different fields on the two axes. We find a strong evidence that the larger the distance from the origin of the coordinate system (i.e. the larger the coordinate value), the more "science-intensive" the field. For a measure of science intensity we made use of recent findings of Olivastro and Narin ([12]; see also [6, pp. 333–337]) where the number of citations in patents to "non-patent" (mostly scientific) literature was used to find a measure of "science intensity" of the technology fields. In a forthcoming publication we will present more details of this possible linkage between position in a co-word structure and the science intensity of a technology field. Our conjecture is that the more science-intensive a field is, the more "exotic" the words in this field are, as compared to the rather "plain" words characterizing the more "classic" fields of technology. In co-word analysis, the more "exotic" words will be positioned at a further distance from the imaginary origin, where the more "plain" words form a cluster. Undoubtedly, further empirical work on co-word mapping of technology is necessary to gain insight into underlying features.

To conclude our macro-view

Returning to the co-classification maps, we notice that the maps (EPAT-based and WPI/L-based) for 1987/1988 do not differ drastically from the maps of 1979/1980, as far as it concerns the main lines. There are three plausible explanations, and probably all three play their part. In the first place, one may state that, on the whole, the relations between the fields of technology indeed did not change to a large extent in the period 1980–1987. Second, classification systems are rather rigid, and not very suitable for monitoring changes in technology. Third, the delineation of the technology fields by the IPC codes is probably of a too aggregated level to reveal finer changes in mutual relations between fields. We maintain, however, that our co-classification maps do give a useful, broad overview of the linkages between fields of technology. Undoubtedly further improvements of our mapping techniques are necessary. The results presented in this report can be seen as first approaches. In sections 3.3 and 4 we indicate the main lines of further possible improvements which are currently investigated in our group.

Nevertheless, our macro-maps show highly interesting features which might be of importance for technology policy and industrial R&D management. We illustrate this with one example. Our macro-maps offer a pictorial *overview* of the whole domain of technology. We already noticed that three main clusters of technology fields immediately strike the eye: a chemical, a mechanical, and an electronical technology cluster. The bridging fields between these technology clusters are clearly visible. For each field of technology its position on the map, defined by its relation and linkages with other fields, can easily be found. Therefore, our mapping method offers a new tool: identification of *technological peripheries*.

With this concept we mean the following. Each field of technology (e.g. coating) is directly "surrounded" by other fields, i.e. those fields most intensively related to it. By lowering specific thresholds of the strength of relations, further peripheries can be identified. This procedure enables us to find out what fields of technology are important for coating in the first place, in a second approximation, and so on. Also the change of the above discussed peripheral structure can be observed. This may give the possibility to recognize in a fast and efficient way the fields that initially were belonging to a more remote periphery, but now are entering the direct surroundings of coating.

3.2 *Affinities of technology fields*

As discussed in the foregoing section, the co-occurrence matrices which form the basis of the co-classification maps, can also be used to calculate numerical values for the affinities between the fields of technology. These affinities (defined in terms of matrix elements in section 2) can be understood straightforwardly: it is the relative number of patents in a specific field of technology (e.g. coatings), belonging at the same time to another field (e.g. polymers). When they are used next to the maps, these affinities add to a better insight into the mutual relations between fields and the strengths of these relations.

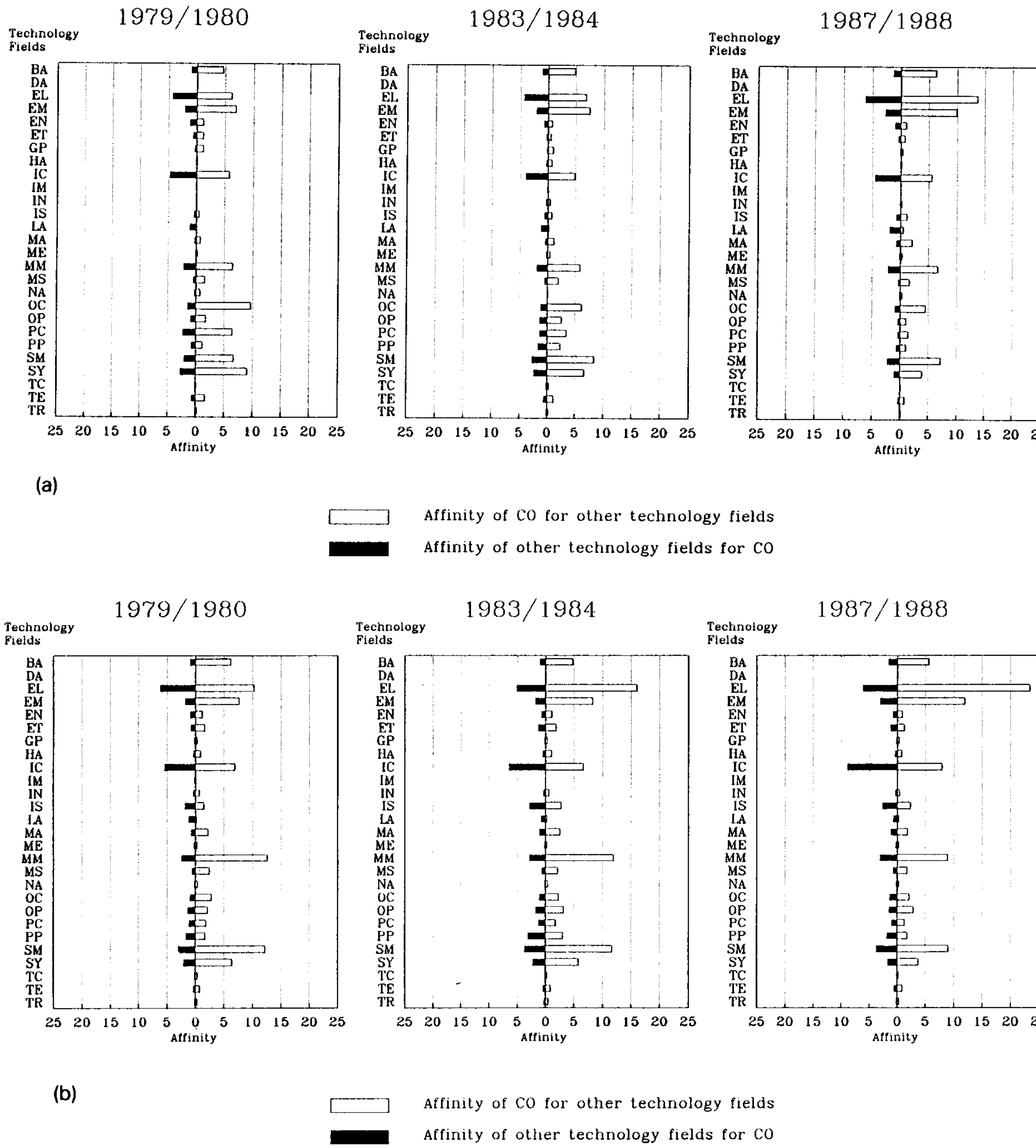
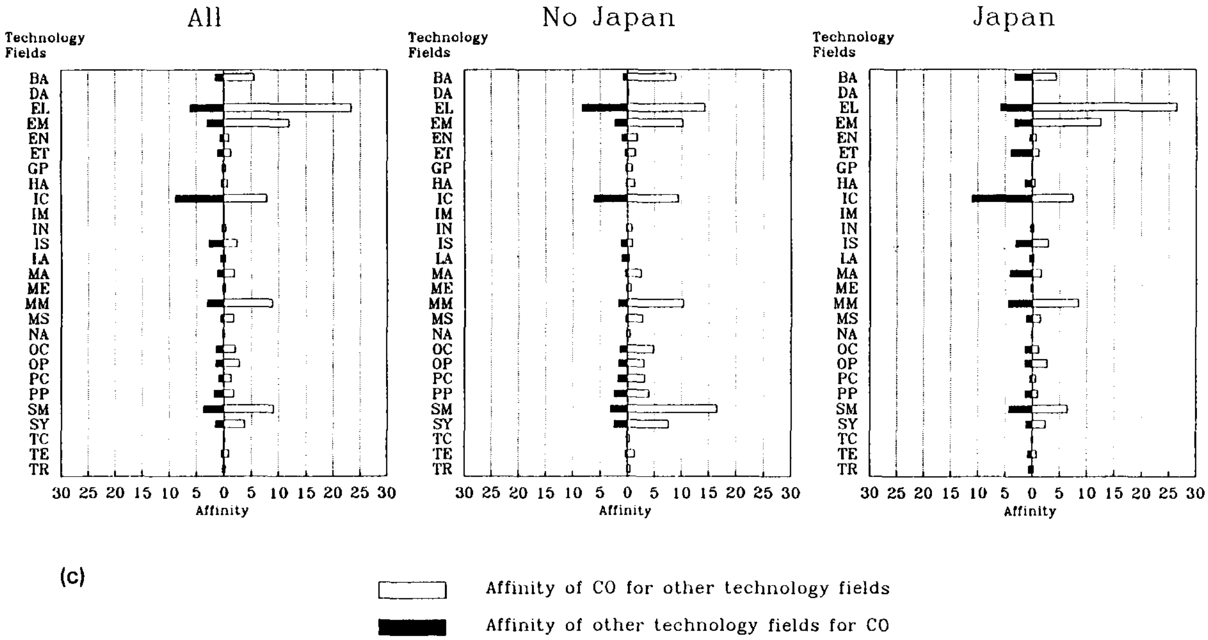


Fig. 6(a). Affinities for EPO patents (database EPAT), technology field CO, for the years 1979/1980, 1983/1984 and 1987/1988. (b) Affinities for patents worldwide (database WPI/L), technology field CO, for the years 1979/1980, 1983/1984 and 1987/1988. (c) Affinities for patents worldwide (database WPI/L), technology field CO, comparison of "world with Japan" ("ALL"), "world without Japan" ("No Japan") and "Japan", for 1987/1988.



(c)

Fig. 6 (continued).

As an example, we determined affinities for the field CO (coating, crystal growing). For a full comparison with the corresponding maps, we determined for each of the four above mentioned technology fields the affinities for the European (EPAT) and the worldwide patent data (WPI/L) for 1979/1980, 1983/1984 and 1987/1988, and in addition for 1987/1988 the "world without Japan" and "only Japan" [1] (both based on WPI/L data).

Coating, crystal growing (CO)

In fig. 6(a) the affinities of the technology field CO (coating, crystal growing) for the European patent data of 1979/1980, 1983/1984 and 1987/1988 are shown. The left-hand side of each part of the "triptych" indicates the *percentage of CO patents in other fields*. We see for instance that in 1979/1980 IC (inorganic chemistry), followed by EL (electronics, electronic components), has the largest percentage of patents that also belong to CO. We notice that in 1987/1988 these roles are reversed. In other words, we could say that nowadays EL (electronics, electronic components) and IC (inorganic chemistry) are the technology fields with the (relatively) strongest linkage with CO (coating, crystal growing).

At the right-hand side the *percentage of patents from other fields within CO* is given. Here we observe that for CO in 1979/1980, SM (process engineering, separation, mixing), OC (organic chemistry, petrochemistry), and SY (manufacturing and application of polymers) are the three most important "other" fields. For 1987/1988, the most striking feature is the strongly increased linkage with EL (electronics, electronic components), especially at the right-hand side, i.e. within CO the number of EL-related patents has increased considerably. In contrast with this, the relation between CO and chemical fields (organic chemistry, polymer chemistry, process engineering, but not inorganic chemistry) has diminished.

When we look at the worldwide patent data (WPI/L, Fig. 6(b)), we see roughly the same features. However, the affinity of IC for CO has increased (left-hand side). Furthermore, it is remarkable that in these worldwide data CO had already in 1979/1980 a larger affinity for IC than for OC (right-hand side), in contrast with the

[1] Japan: patents with a Japanese first priority, i.e. domestic and foreign applications in Japan.

European data. In the middle panels of our triptychs, both for the European and for the worldwide data, we see that the period 1983/1984 shows a profile which is generally in between the earlier and the recent period. This suggests that our affinities are not too "noisy" and that they can be used for analysing trends. The role of Japan for 1987/1988 is illustrated by fig. 6(c). The large influence of electronics in Japanese CO patents is clearly visible.

3.3. Maps of technology on a meso- and micro-scale

The above findings suggest that monitoring at a more disaggregated level would be appropriate to disclose finer patterns of technological change. Therefore, maps have been constructed at the meso- (a specific combination of several fields) and at the micro- (one specific field) level. For this purpose, we used co-word analysis. The use of words is independent of classification systems and gives the opportunity to make comparisons with the "scientific part" of the R&D field under study [11].

First we present the results at the micro-level: co-word maps for the fields OP (optical equipment), CO (coating, crystal growing), and BA (mining, civil engineering, building materials, etc.). Coating and crystal growing is chosen because it is an important field of technology with many new developments, rather specialized and therefore small in size (in terms of numbers of patents), but showing interesting relations with many different fields of technology, both "high" as well as "medium tech" Mining and civil engineering is chosen because it is an example of a "classic" field, large in size and undoubtedly of basic economic importance. It is fascinating to see that even in such a "classic" field our mapping technique clearly reveals important innovations and technological improvements. Furthermore, a presentation of the result for a combina-

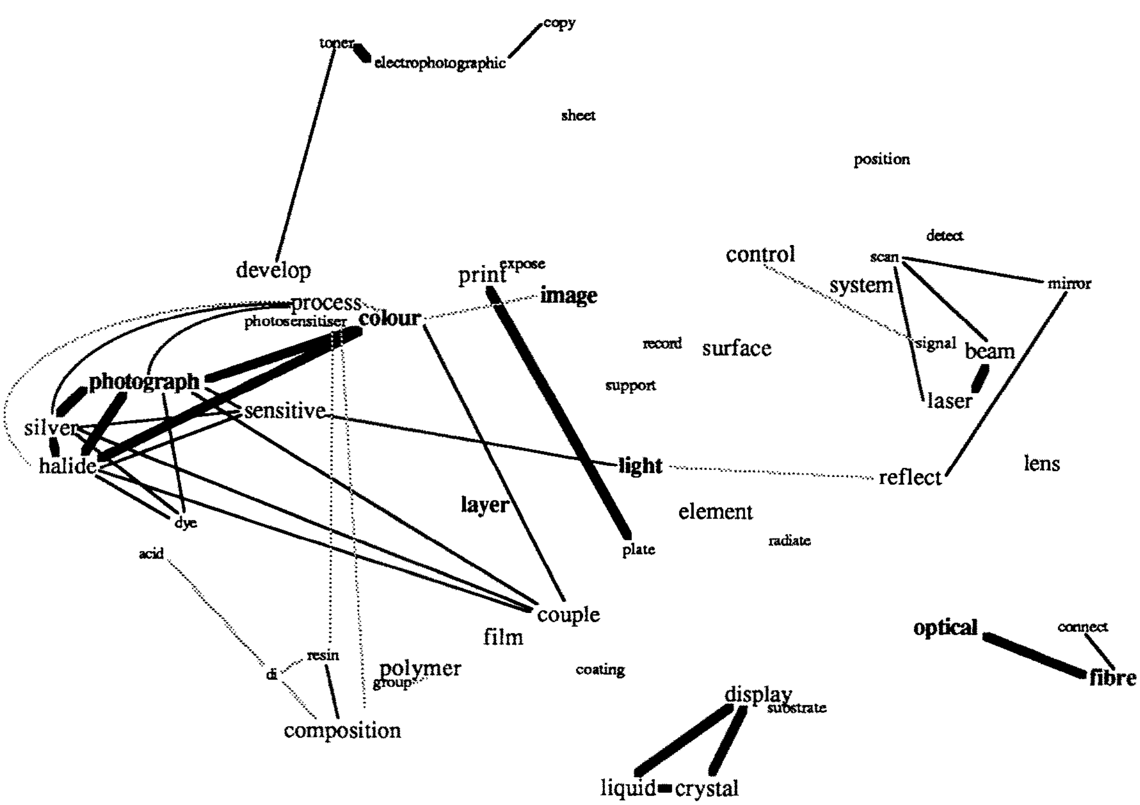


Fig. 7. Co-word map for the technology field OP, database WPI/L (1987). (Legend see fig. 10.)

tion of the fields HA, MS, and OP is given, which combination is considered as a first and preliminary definition of the recent and strongly emerging "crossroad" technology named "optomechatronics".

Co-word mapping puts keywords with the strongest linkages together. In this way clusters of related words can be formed. Our maps are a first step in an ongoing development towards a better "bibliometric cartography".

Optical equipment (OP)

A fascinating image of the field OP (optical equipment) is given by the map in fig. 7. Here we see clusters around laser-beam scanning, photography and print plates, xeroxing, liquid crystal displays, and optical fibers. The xeroxing techniques are positioned closely near photography (through the keyword "develop"). We hypothesize that these clusters constitute specific centers of technological activity, or even "innovation centers", within the field concerned.

Coating, crystal growing (CO)

In fig. 8 the co-word map of the technology field CO (coating, crystal growing) is shown. Also in this map we see different clusters. Some are related to specific coating techniques (plasma etching, vapour deposition), other indicate "problem areas" (corrosion by acid/water), or specific "products" such as superconducting thin films.

We remark that painting and synthetic resins are not represented in the map. It is a consequence of our definition of this field by specific IPC codes (see table 1).

Mining, civil engineering, building materials (BA)

The above discussed fields are all characterized by dominating "high-tech" aspects. At this point, it is fascinating to show a map of a more "classic" and medium- to low-tech field such as

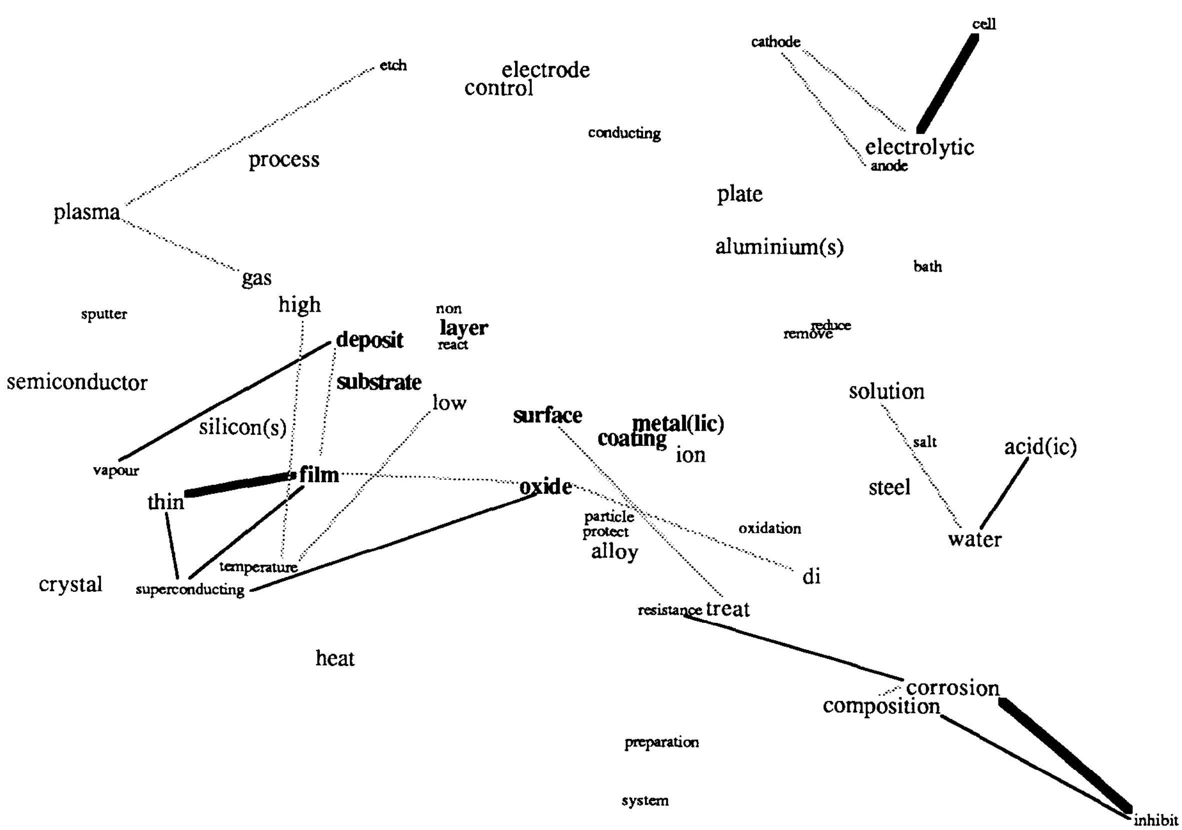


Fig. 8. Co-word map for the technology field CO, database WPI/L (1987). (Legend see fig. 10.)

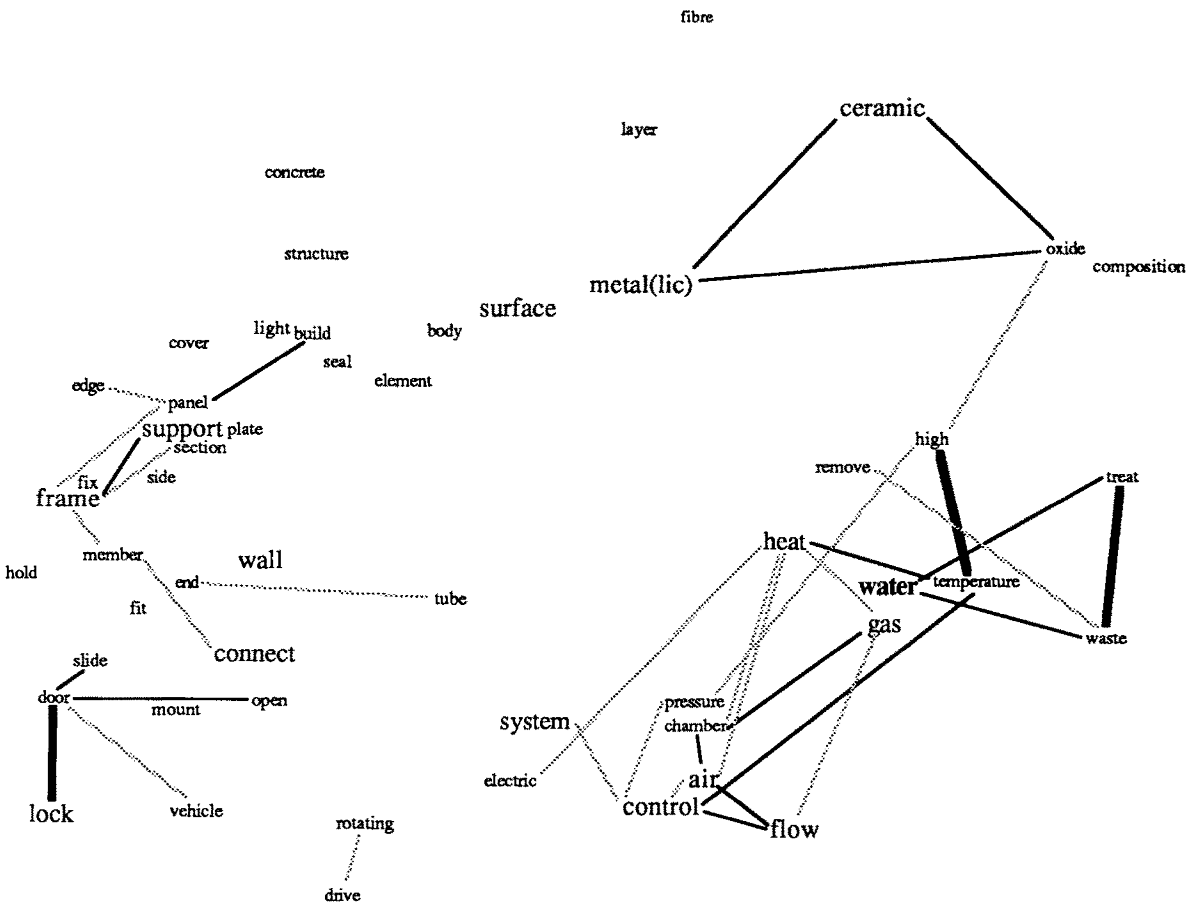


Fig. 9. Co-word map for the technology field BA, database WPI/L (1987). (Legend see fig. 10.)

BA (mining, civil engineering, building materials, etc.). This map is shown in fig. 9. We immediately note that a very "old-fashioned" topic such as "door locks" is still an "innovation center" on this map. But we also see a cluster of new materials (metallic, ceramic) and a large cluster related to important building facilities such as heat, water, air, and gas control systems.

Optomechatronics

As discussed earlier, the combination of the fields HA (handling, conveyor equipment, robots), MS (metrology, sensors), and OP (optical equipment) is considered to be defining, in first approximation, the "crossroad" technology optomechatronics. Certainly this HA-MS-OP combination will not fully cover the entire range of optomechatronics R & D activities.

In our first approach to map the field of optomechatronics, we proceeded along three lines. First, a co-word map of the above HA-MS-OP combination was made (priority year 1987, patent database WPI/L). We call this map the "optomechatronics technology map" (fig. 10). Second, we searched for the word "(opto)mechatronics" in the physics and electronics (applied) scientific literature (via database INSPEC, publication year 1987) and established the most frequently occurring keywords in these (opto) mechatronics publications. We used these most important and meaningful words to delineate a larger set and determined the 50 most frequently occurring keywords in this larger set. Although "mechatronics" did not occur among "top-ten" keywords (obviously, the term "mechatronics" was not yet generally accepted in 1987), this larger set of words reflected remarkably well the topics mentioned by expert review of the European Community (see [11]). With these 50 keywords, we performed a co-word analysis and constructed an "optomechatronics research map" (fig. 11). Third, the set of nine most important words as mentioned in the foregoing step was used to identify patents in the WPI/L database. For these the foregoing step was used to identify patents in the WPI/L database. For these "optomechatronics" related patents, we established the most frequent keywords in WPI/L and again made a co-word map. In this way a second patent-based map was constructed (next to the map based on the HA-MS-OP combination), but this time these words were not derived from a set of patents in a chosen combination of technology fields, but from a set of patents defined by keywords from the (applied) scientific literature. We call this map (fig. 12) the "optomechatronics science and technology interface map".

There is no doubt that the three maps are quite different. When we look at the "technology map" (HA-MS-OP combination) in fig. 10, we see an important cluster (upper left-hand side) related to (position) alignment of patterns for semiconductor wafers, in close relation with specific optical techniques (fibres, laser-beam scanning).

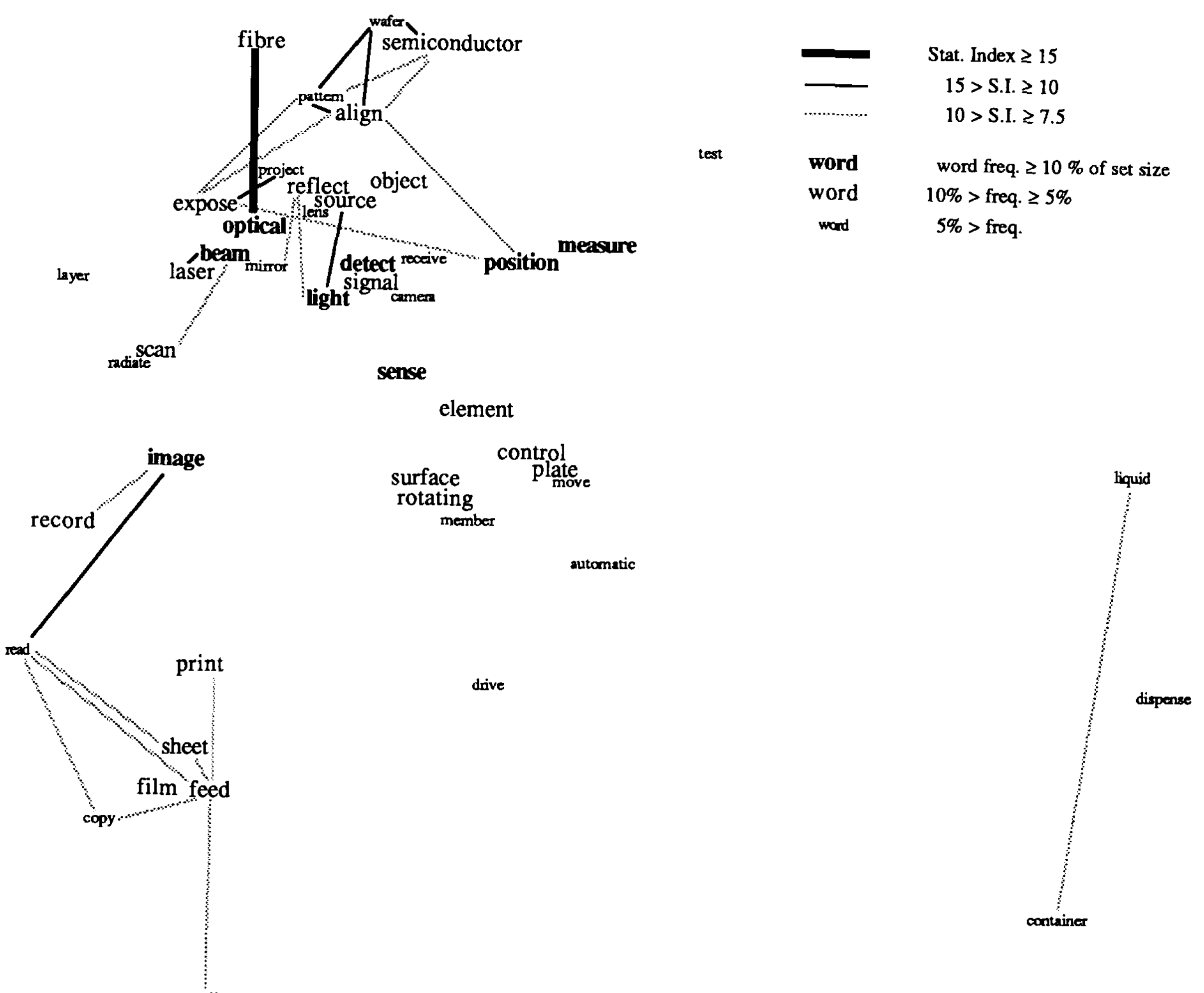


Fig. 10. Co-word map for optomechatronics (1987) as represented by the combined technology fields HA, MS and OP (database WPI/L).

Furthermore, a cluster of storage and copy technology (recording images, sheet feeders) is visible at the lower left-hand side. The remainder of the figure shows rather "dispersed topics".

In fig. 11 the "optomechatronics research map" is shown. As discussed above, we determined the nine most important keywords (title words, abstract words, controlled terms) originating from publications (1987) in the INSPEC (physics and electronics) database with the "optomechatronics" or "mechatronics" associated with them.

By using this set of nine keywords for a further search in INSPEC, we collected all "second order" optomechatronics-related publications. The co-occurrence of all keywords in these publications forms the basis of the optomechatronics research map. The first impression of the research map is that there are three main clusters. Furthermore, some form of dimensionality may be recognized, represented by an imaginary horizontal axis. At the upper left-hand side we notice a "user-system interface" cluster, with subjects as CAE (Computer Aided Engineering), engineering computing, CAD/CAM, workstations, graphics, software development. This cluster marks an important part of optomechatronics, in particular the electronic transmission of CAE data, for instance interfaces for different CAD/CAM systems. At the centre, reaching out towards the bottom left-hand side, a typical "systems" cluster can be recognized, with subjects as LAN (Local Area Network), MAP (Manufacturing Automation Protocol), FMS (Flexible Manufacturing Systems), computer control, AI (Artificial Intelligence), expert systems, and so on. Finally, at the right-hand side we notice a "system-product interface" cluster, with subjects as positioning, manipulation, servomechanisms, motion control, robots (with sensory functions such as "vision") for welding and assembling. It is remarkable that optical systems are almost absent in this map, except for vision techniques related to robotics.

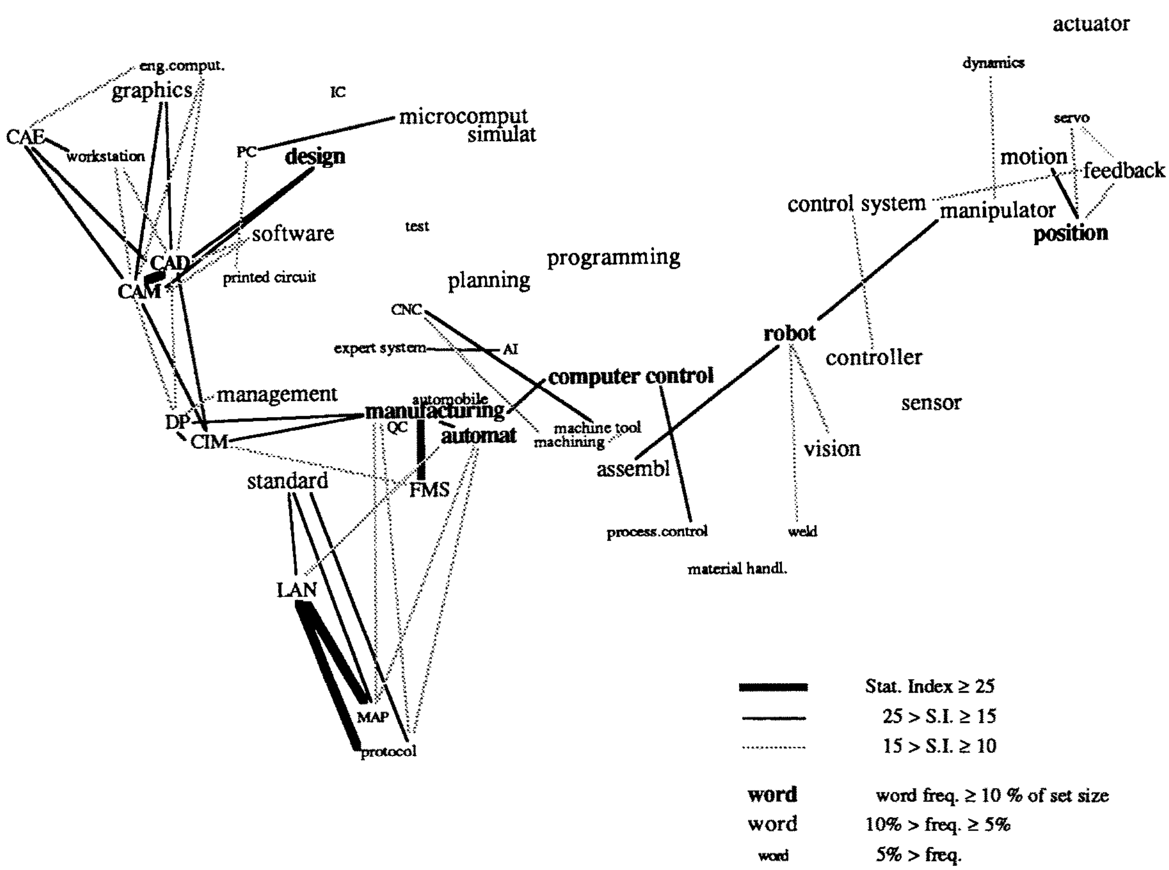


Fig. 11. Co-word map for (opto)mechatronics (research map), database INSPEC (1987).

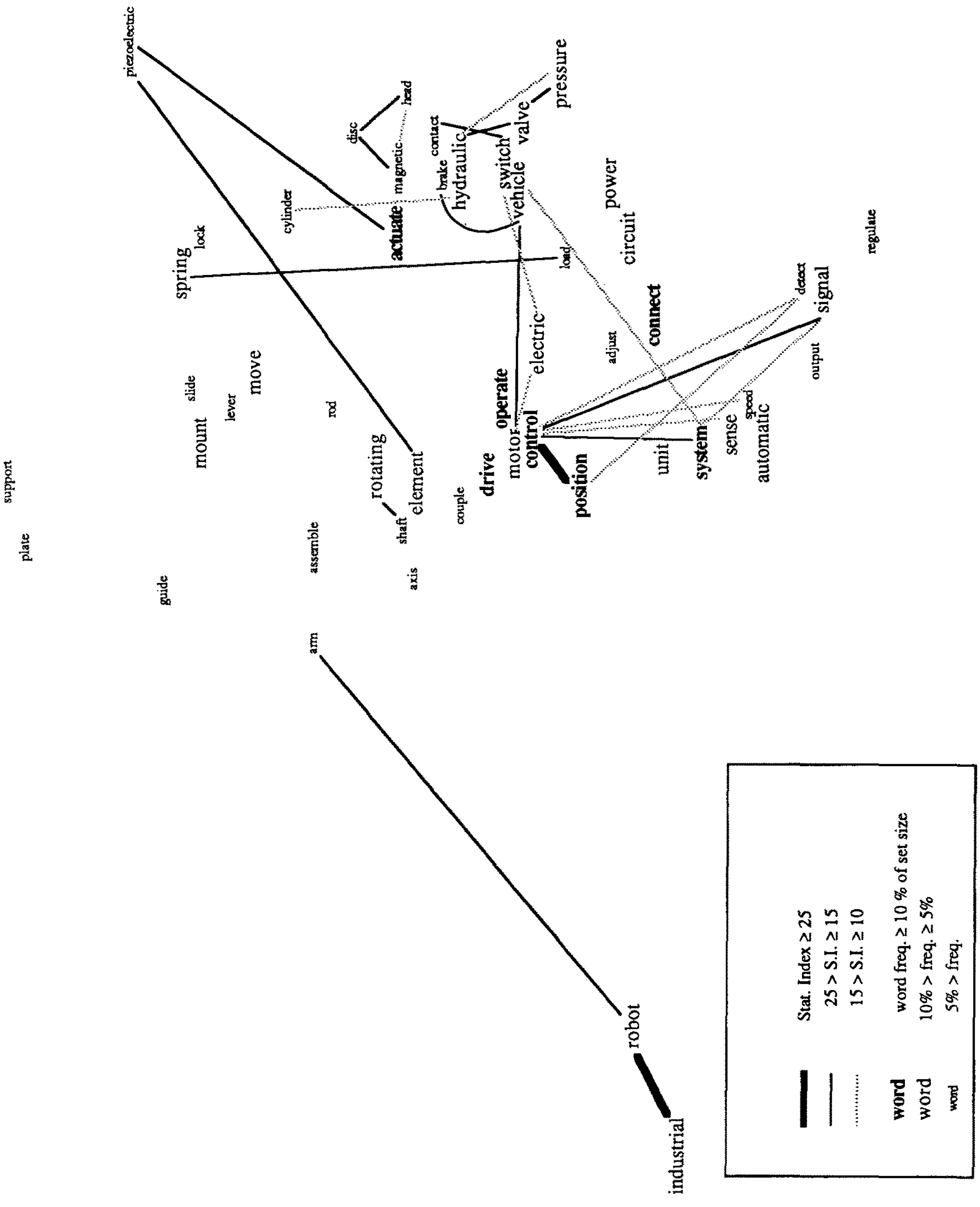


Fig. 12. Co-word map for the optomechatronics science and technology interface, database WPI/L (1987).

The focus is much more on electronics, computing and automation. Our first conclusion is that there is a fairly large discrepancy between the chosen technology fields (HA-MS-OP) to define optomechatronics, and the activities involved in (opto)mechatronics as established from the (applied) scientific literature. Indeed, the word "optomechatronics" is hardly present in the INSPEC database, the primary keyword is "mechatronics". This indicates that the addition of the technology field OP (optical equipment) to HA (handling, conveyor equipment, robots) and MS (metrology, sensors) in order to create a technological "optomechatronics" field, is rather arbitrary, "just to include optics". It is the field OP which puts the optical fibers and laser beam scanning on the technology map (fig. 10). In the optomechatronics research map (fig. 11) the optical part is, as discussed above, limited to a rather modest contribution of vision in relation to robotics. Nevertheless, this modest position of "opto" in "mechatronics" does not necessarily reflect its actual and future importance. It may indicate that "opto" in "mechatronics" is a "pious hope", but technologically (and scientifically!) a major problem. We notice, however, that our mapping of optomechatronics is a first exploration. Current work is going on [11] to improve the maps by more precise delimitation of the R&D fields.

The set of INSPEC keywords was also used for the third map, for which the WPI/L database (1987) was scanned for patents characterized by one or more of these keywords. For the patents collected in this way, we analysed the co-occurrence of all embodied keywords. This means that a second patent-based optomechatronics co-word map was constructed. This time, however, the patents were selected by the terminology as used in the (applied) scientific literature. This "optomechatronics science and technology interface" map is shown in fig. 12. In this figure, we again see the important position of positioning and control systems. A striking point now is the rather isolated location of robotics. We remark that in the optomechatronics technology map (HA-MS-OP), robotics is virtually absent, whereas in the optomechatronics research map it takes a quite central position. In the optomechatronics science and technology interface map the emphasis is on electronically controlled mechanical systems (rotating elements, motor control, hydraulic systems, actuators, etc.). Some of the encountered differences between the maps may be explained by the difference in character of the three approaches. For example, there may be a large number of robot-related experimental designs that result in separate scientific papers, but that does not imply that there will be a large number of robot-related patents.

However, in our opinion not all differences in the three optomechatronics maps can be explained simply by pointing out the different bases of maps: "technology", "science", and "science and technology interface". Although optomechatronics undoubtedly represents a rather heterogeneous field of R&D activities, our present maps show too divergent pictures of this field. Most probably, the set of patents (and of publications) maps offer an important starting point to tackle the problem: the maps do show common features (in particular position and motion control technology) and this result should be used as an input for a second approach. Mapping of technology, and especially of "high-tech" fields, implicates the mapping of R&D activities in which data from (applied) research publications are just as important as patent data. Forthcoming work in our group will focus on this problem.

Therefore, we emphasize that our meso- and macro-maps are first approaches and that they are preliminary. But these first approaches are necessary to understand how the mapping techniques can be improved. We expect that current work in our group on a more sophisticated combination of different multivariate analysis techniques, as well as the combination of patent and publication data sources, will indeed yield further progress in the construction of technology maps.

4. Conclusions

Mapping of technology by using patent data has its strengths and weaknesses. Apart from data analytical and statistical problems, the weak sides are, of course, primarily related to the common basis of the maps: patents. Although patents contain a wealth of data, their use in describing technological developments is hampered by several problems. In particular, not all innovating activities are patented. There are differences in "patenting behaviour" between fields of technology, between various stages of the innovation process, but also between countries and companies. A considerable improvement is the inclusion of publication data, in particular from the "(applied) science side" and "engineering side" of an R&D field. In this paper we show first examples of such an approach for the field of optomechatronics. Our work shows that mapping of technology based on patents does provide important information and allows for

- observation of the *structure of technology* as a whole, i.e. the mutual relations between all fields of technology, as well as the changes over time;
- identification of technology fields with a specific *central* or *bridge* function (or with a strong interdisciplinary character), and again the changes over time;
- investigation of the *technological periphery* of a specific field, in order to know the direct as well as the more remote surroundings of the field, and the changes of this periphery;
- visualization of the *internal structure* of a technology field, or combination of fields, which offers the possibility to identify *centers of innovative activity*.

In this publication we report our first approaches to construct technology maps. The results show the feasibility of monitoring technological developments based on patent data. Current research in our group is aiming at a further improvement of mapping techniques. For instance, the sophisticated combination of different multivariate analysis techniques is promising. Parallel to these technical advances, the inclusion of publication data is a further, very important improvement, in particular for the high-tech fields, as we showed for optomechatronics R&D. In fact, this combination of publication and patent data will shift our analytical methods from the technological domain toward the interface of science and technology, the nursery of all R&D activities [21].

We expect that our work will contribute substantially to the exploration of bibliometric methods for the analysis of the many aspects of technological and, more specifically, R&D development. The "structuring" of new knowledge is one of these aspects. Bibliometric cartography provides a new analytical tool in the investigation of cognitive development of scientific and technological knowledge.

The importance of the work presented in this paper and further developments is twofold. First, at the "application side", the above results indicate that bibliometric cartography of technology may provide R&D management and science and technology with an *observatory* as a support tool for decision making. Second, at the more "basic side", we think that our work will improve substantially the understanding of the complex, dynamical processes in technology and its interaction with science. We are currently using mapping techniques to study the interface of science and technology as a self-organizing, "ecological" system [20,21], based on our earlier empirical findings of fractal properties of the science system [18].

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