Statistics on Image Engineering Literatures

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INTRODUCTION

Images are an important medium from which human beings observe the majority of the information they received from the real world. In its general sense, the word "image" could include all entities that can be visualized by human eyes, such as a still image or picture, a clip of video, as well as graphics, animations, cartoons, charts, drawings, paintings, even also text, *etc*. Nowadays, with the progress of information science and society, "image" rather than "picture" is used because computers store numerical images of a picture or scene.

Image techniques are those techniques that have been invented, designed, developed, implemented and used to treat various types of images for different and specified purposes (Zhang, 2009b). They are expanding over wider and wider application areas. They have attracted more and more attention in recent years with the fast advances of mathematic theories and physical principles, as well as the progress of computer and electronic devices, etc. Image engineering (IE), an integrated discipline/subject comprising the study of all the different branches of image techniques, which has been formally proposed and defined around 20 years ago (Zhang 1996a; Zhang 1996c) to cover the whole domain, is evolving quickly.

In the history, a well-known bibliography series to some related image techniques had been developed to offer a convenient compendium of the research in picture processing from 1969 till 1986, as well as in image processing and computer vision after 1986. This series has been ended in 2000 by the author after a total of 30 survey papers were published (Rosenfeld, 2000). Some limitations of this series are (Zhang, 2002b):

1. No attempt was made to summarize the cited references for each year.
2. No attempt was made to analysis the distributions of the selected references from various sources.
3. No attempt was made to provide statistics about the classified references in each group.

Another survey series, but on IE (with more wider coverage in the contents), have been started since 1996 and have been made already for consecutive 18 years (Zhang, 1996a; Zhang, 1996b; Zhang, 1997; Zhang, 1998; Zhang, 1999; Zhang, 2000a; Zhang, 2001; Zhang, 2002a; Zhang, 2003; Zhang, 2004; Zhang, 2005; Zhang, 2006; Zhang, 2007; Zhang, 2008a; Zhang, 2009a; Zhang, 2010; Zhang, 2011a; Zhang, 2012, Zhang, 2013). The summaries for several stages of this survey series can be found in (Zhang, 2000b; Zhang, 2002b; Zhang 2002c; Zhang 2008b; Zhang 2011b).

The main purpose of this survey work is triple, that is, to capture the up-to-date development of IE, to make available a convenient means of literature searching facility for readers working in related areas, and to supply a useful reference for the editors of journals and potential authors of papers. This new series overcome the weakness of the above-mentioned one by summarizing the cited references for each year, analyzing the distributions of the selected references from various sources and providing various statistics about the classified references in each subject group. This new survey series has already made consecutively for eighteen years. This article will present an overview of this survey series by showing the ideas behind and consideration on this work, as well as the comprehensive statistics obtained from this work. Some insights from it are also discussed.

BACKGROUND

For image engineering, a new discipline, the scope and related subjects are first described.

DOI: 10.4018/978-1-4666-5888-2.ch595

Scope of IE

IE, from a perspective more oriented to technique, could be referred to as the collection of three related and partially overlapped groups of image techniques, that is, Image Processing (IP) techniques, Image Analysis (IA) techniques and Image Understanding (IU) techniques. In a structural sense, IP, IA and IU build up three inter-connected layers of IE as shown in Figure 1. Each of them operates on different elements (IP's operand is pixel, IA's operand is object, and IU's operand is symbol) and works with altered semantic levels (from low at IP, via middle at IA, and to high at IU). The three layers follow a progression of increasing abstractness (left up arrow) and of decreasing compactness (right down arrow) from IP to IA to IU.

The techniques covered by IP primarily include the acquisition, representation, compression, enhancement, restoration and reconstruction of images. While IP is concerned with the manipulation of an image to produce another (improved) image, the techniques covered by IA are more concerned with the extraction of information from an image (especially from the objects in it). Compared to IP that takes an image as input and outputs also images, IA takes also an image as input but outputs data extracted from input. Here, the data can be the measurement results associated with specific image properties or the representative symbols of certain object attributes. Based on IA, IU refers to a body of knowledge used in transforming the data into certain commonly understood descriptions, and for making subsequent decisions and actions according to the interpretation of the image contents.

Related Subjects

IE is a broad subject encompassing studies related to mathematics, physics, biology, physiology, psychology, electrical engineering, computer science, automation, *etc*. Its advances are closely related to the development of telecommunications, biomedical engineering, remote sensing, document processing, industrial applications, *etc*. (Zhang, 2002b; Zhang, 2013).

According to different science politics/perspectives, various terms such as Computer Graphics (CG), Pattern Recognition (PR), Computer Vision (CV), Scene Analysis (SA, just counted as another name of CV, see Rosenfeld, 2001) *etc*., are (partially) overlapped with IP, IA and/or IU. A diagram describing the relationship among the above-mentioned subjects is given in Figure 2. Images are captured from the real world and processed (with IP techniques) to furnish the basis for IA or PR. The former produces data that can be visualized by CG techniques, while the latter continually classifies them into one of several categories. Results produced by both of them can be further interpreted for human beings to understand the real world. The whole process aims to make computers capable of understanding environments from visual information, which is also the purpose of CV/SA.

Figure 1. Three layers of image engineering

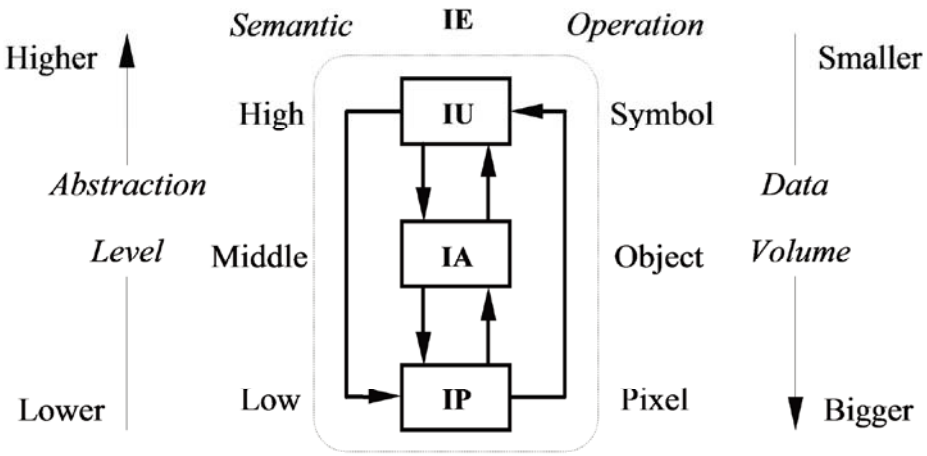
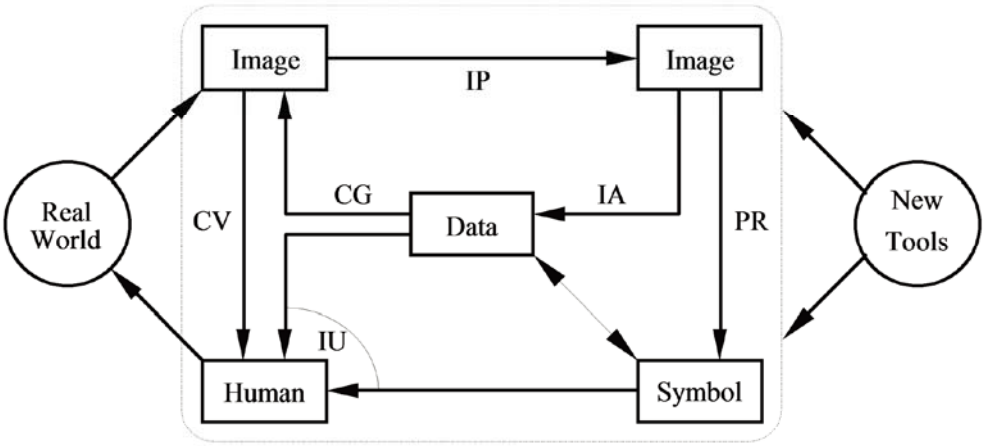


Figure 2. Image engineering and related subjects



STATISTICS ON IMAGE ENGINEERING LITERATURES

After many years of development, IE (including IP, IA, and IU) has been greatly progressed. What is the current "picture" of IE? Answering this question is the foremost intention of the new survey series. For such a purpose, selection of reference source and classification of references according to their contents are two important factors. Also for such a purpose, three statistics made by this survey are illustrated in the following.

Classification Scheme

The classification scheme used in the bibliography series should reflect the contents of references. A classification problem can be considered as a problem of partitioning a set into subsets. An appropriate classification of references into groups and/or sub-groups should satisfy the following four conditions:

1. Every reference must be in a group.
2. All groups together could include all references.
3. The references in the same group should have some common properties.
4. The references in different groups should have certain distinguishing properties.

Taking into consideration the above four conditions and the current status of IE development in the field, a complete and compact classification of the theories and techniques of IE is proposed and listed in Table 1 (Zhang, 2006). It is easy to verify that the above four conditions are fulfilled by this classification.

Source Selection

As with any other emerging discipline, a large number of references related to IE have been published worldwide. The continued growth of the literature has already made it impractical to cover all of them in one survey (Rosenfeld, 1999). Though references have been dispersed across many resources, the most popular ones are conference proceedings, journals and books. Considering the fast publishing rate, the conference proceedings would be ranked first, followed by journals and books. Considering the comprehensiveness, the books would be ranked first, followed by journals and conference proceedings. Considering the quality, coverage, and regularity (which is important for a yearly survey), journal articles would be ranked higher than that of conference proceedings and books. Combining all these consideration, journals would be a better choice for such a survey series.

Based on a careful selection of literatures for providing an appropriate coverage in this area, 15 important journals (in the sense defined by Lin, 1996) with high standard articles that are published in Chinese have been selected to limit the volume of references to a manageable size. All of the papers in these journals have titles, abstracts and keywords in English. The list of journals is given in Table 2.

Table 1. Classification scheme of image engineering

Group	Sub-Group
IP: Image Processing	**P1:** Image capturing (including camera models and calibration) and storage **P2:** Image reconstruction from projections or indirect sensing **P3:** Filtering, transformation, enhancement, restoration, inpainting, *etc.* **P4:** Image and/or video coding/decoding and international coding standards **P5:** Image digital watermarking, forensic, image information hiding, *etc.* **P6:** Image processing with multiple-resolutions (super-resolution, decomposition and interpolation, resolution conversion, *etc.*)
IA: Image Analysis	**A1:** Edge, corner detection, image segmentation **A2:** Representation, description, measurement of objects (bi-level image) **A3:** Analysis and feature measurement of color, shape, texture, position, structure, motion, *etc.* **A4:** (2-D) object extraction, tracking, discrimination, classification and recognition **A5:** Human face and organ (biometrics) detection, location, identification, categorization, *etc.*
IU: Image Understanding	**U1:** (Sequential, volumetric) image registration, matching and fusion **U2:** 3-D modeling, representation and real world/scene recovery **U3:** Image perception, interpretation and reasoning (semantic, expert system, machine learning) **U4:** Content-based image and video retrieval (in various levels) **U5:** Spatial-temporal technology (high-dimensional motion analysis, 3-D gesture detection, tracking, manners judgment and behavior understanding, *etc.*)
TA: Technique Applications	**T1:** System and hardware (fast algorithm implementation) **T2:** Telecommunication, television, web transmission, *etc.* **T3:** Documents (texts, digits, symbols) **T4:** Bio-medical imaging and application **T5:** Remote sensing, surveying and mapping **T6:** Other areas

Table 2. Selected journals

#	Journal	Abbreviation.	Current Cycle
1	Acta Automatica Sinica	AAS	Monthly
2	Acta Electronica Sinica	AES	Monthly
3	Acta Geodactica et Cartographica Sinica	AGCS	Bimonthly
4	Chinese Journal of Biomedical Engineering	CJBE	Bimonthly
5	Chinese Journal of Computers	CJC	Monthly
6	Chinese Journal of Stereology and Image Analysis	CJSIA	Quarterly
7	Computerized Tomography Theory and Applications	CTTA	Quarterly
8	Journal of China Institute of Communications	JCIC	Monthly
9	Journal of Data Acquisition and Processing	JDAP	Bimonthly
10	Journal of Electronic Measurement and Instrument	JEMI	Monthly
11	Journal of Electronics and Information	JEI	Monthly
12	Journal of Image and Graphics	JIG	Monthly
13	Journal of Remote Sensing	JRS	Bimonthly
14	Pattern Recognition and Artificial Intelligence	PRAI	Bimonthly
15	Signal Processing	SP	Monthly

Summary over Years

The first statistic made from this survey series is a summary of the number of publications in the last eighteen years, as shown in Table 3.

As in a survey of papers, the references have been classified into five groups: IP, IA, IU, TA and Survey. In Table 3, the total number of papers published in the selected journals (#T), the number of papers selected for survey as they are related to IE (#S), and the selection ratio (SR), which equals to #S/#T, for each year have been provided. In addition, the paper numbers for five groups (and their percentages in the year) are also listed.

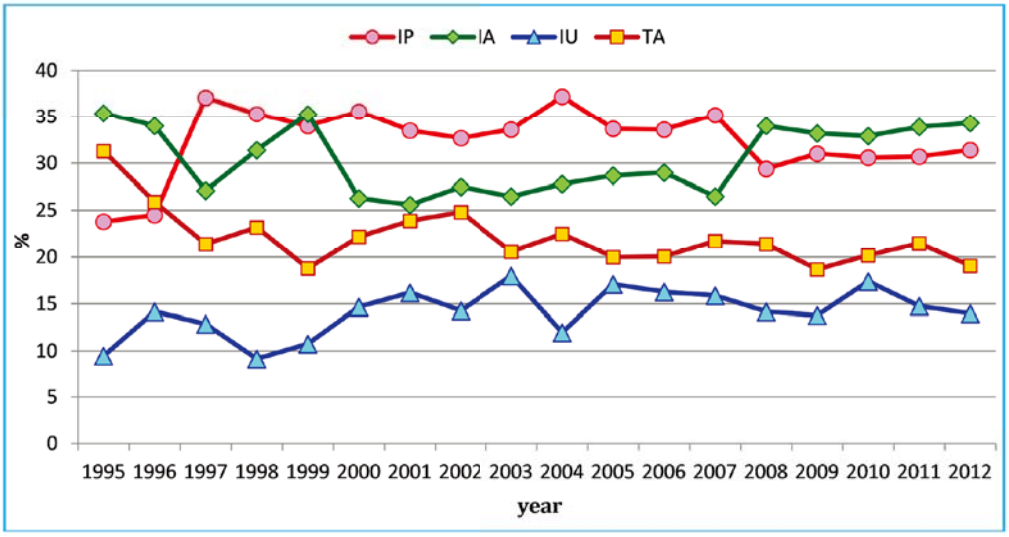
Some interesting points can be noted from Table 3:

1. This work has attended a quite large scale, with more than 41000 papers involved and nearly 10000 papers selected and classified (nearly 50 papers per month).
2. IE is an (more and more) important topic for electronic engineering, computer science and automation. The average SR is more than 1/5 (many recent years it is more than 1/4), which is remarkable considering the wide coverage of these journals.
3. IE publication evolves quite steadily. From Table 3, #S is increasing almost every year, and its value in 2009 is near 7 times bigger compared to that in the starting year (while the #T in the same year is only 3.6 times bigger compared to that in the starting year). The literature for IE evolves fast than other related disciple/subjects.
4. The growing rates of publications for IP, IA, IU and TA are comparable. To make it clear, Figure 3 shows the numbers of publications for these four groups graphically. The four curves in Figure 1 run quite smoothly and have not intercrossed in

Table 3. Summary over the last eighteen years

Year	#T	#S	SR	IP	IA	IU	TA	Survey
1995	997	147	14.74	35(23.8%)	52(35.4%)	14(9.52%)	46(31.3%)	0
1996	1205	212	17.59	52(24.5%)	72(34.0%)	30(14.2%)	55(25.9%)	3(1.42%)
1997	1438	280	19.47	104(37.1%)	76(27.1%)	36(12.9%)	60(21.4%)	4(1.43%)
1998	1477	306	20.72	108(35.3%)	96(31.4%)	28(9.15%)	71(23.2%)	3(0.98%)
1999	2048	388	18.95	132(34.0%)	137(35.3%)	42(10.8%)	73(18.8%)	4(1.03%)
2000	2117	464	21.92	165(35.6%)	122(26.3%)	68(14.7%)	103(22.2%)	6(1.29%)
2001	2297	481	20.94	161(33.5%)	123(25.6%)	78(16.2%)	115(23.9%)	4(0.83%)
2002	2426	545	22.46	178(32.7%)	150(27.5%)	77(14.3%)	135(24.8%)	5(0.92%)
2003	2341	577	24.65	194(33.6%)	153(26.5%)	104(18.0%)	119(20.6%)	7(1.21%)
2004	2473	632	25.60	235(37.2%)	176(27.8%)	76(12.0%)	142(22.5%)	3(0.47%)
2005	2734	656	23.99	221(33.7%)	188(28.7%)	112(17.1%)	131(20.0%)	4(0.61%)
2006	3013	711	23.60	239(33.6%)	206(29.0%)	116(16.3%)	143(20.1%)	7(0.98%)
2007	3312	895	27.02	315(35.2%)	237(26.5%)	142(15.9%)	194(21.7%)	7(0.78%)
2008	3359	915	27.24	269(29.4%)	311(34.0%)	130(14.2%)	196(21.4%)	9(0.98%)
2009	3604	1008	27.97	312(31.0%)	335(33.2%)	139(13.8%)	214(21.2%)	8(0.79%)
2010	3251	782	24.05	239(30.6%)	257(32.9%)	136(17.4%)	146(18.7%)	4(0.51%)
2011	3215	797	24.79	245(30.7%)	270(33.9%)	118(14.8%)	161(20.2%)	3(0.38%)
2012	2912	792	27.20	249(31.4%)	272(34.3%)	111(14.0%)	151(19.1%)	9(1.14%)
Total	44219	10588	–	3204 (32.61)	2961 (30.53)	1446 (14.71)	2255 (21.30)	90 (1.14)
Average	**2457**	**588**	**23.94**	**192**	**180**	**80**	**125**	**5**

Figure 3. Number variation of the first four groups of IE literatures in selected publications for last eighteen years



last five years (becoming stable), with the rank from top to bottom: IA, IP, TA and IU.

5. The number of publications for IP and IA constitute near 2/3 of the total number of IE publications. This shows that the current research focus of IE. In contrast, research work on IU needs to be promoted.

Distribution Analysis

The second statistic is the summary over the different journals (see Table 2), and the results are shown in Table 4. In Table 4, #I is the number of surveyed issues, #T and #S are now the total number of papers and the number of survey-selected papers, respectively. The rank of the different journals according to their SR (selection ratio), and the rank of the different journals according to their TR (total ratio, *i.e.*, over all 15 journals) are given (they are also depicted in Figure 4). In Table 4, SR gives the relative frequency of IE publications in a journal. This relative frequency brings a measure of the probability of obtaining useful information from that journal. In Table 4, TR presents the relative contribution of each journal to IE publication and supplies a figure of importance of that journal among 15 journals. According to these rankings, readers could selectively scan the journal and judge the value of each journal.

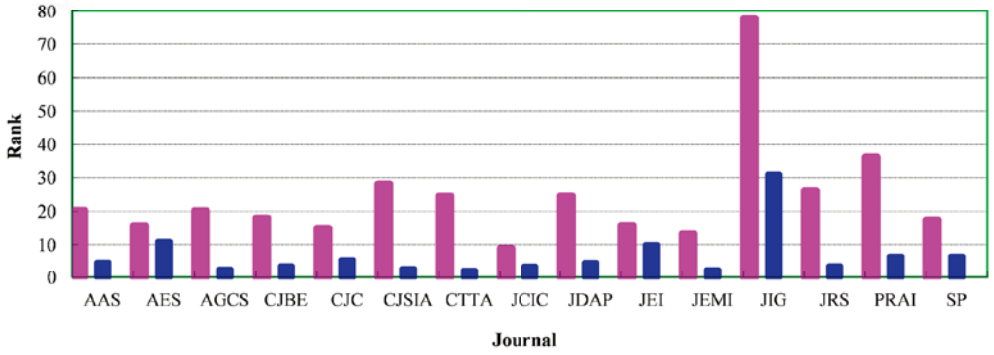
From Table 4, the following observations can be made:

1. SR of a journal gives the probability of obtaining useful information from this journal. JIG has the highest SR among the 15 journals, and therefore it should be checked frequently. The second and third places are occupied by PRAI and CJSIA, respectively.
2. TR of a journal shows the contribution of this journal to IE publication. JIG has the highest TR among the 15 journals (and much higher than all competitors); therefore, it is evident that this journal offers a focused location for researchers in this field. The second and third places are occupied by AES and JEI, respectively.
3. Figure 4 depicts the SR (left) and TR (right) bars for each journal. It is seen not only the relative concentration of publications over different journals, but also the difference between SR and TR, that is, these two rankings for each journal are not propositional, as the volume of journal plays also an role.
4. According to the scatter rule (Ding, 1993), most research papers of one discipline will be concentrated in a few number of journals, and other papers will be dispersed in a large number of journals. The leading five journals: JIG, AES, JEI, SP, and PRAI contained nearly twice the number of IE papers compared to the other ten journals.

Table 4. Summary over distribution among 15 journals

Journal	#I	#T	#S	SR (Rank)	TR (Rank)
AAS	144	2444	494	20.21% (7)	4.67% (7)
AES	184	7374	1160	15.73% (12)	10.96% (2)
AGCS	80	1344	269	20.01% (8)	2.54% (13)
CJBE	96	2118	381	17.99% (9)	3.60% (10)
CJC	216	3873	577	14.90% (13)	5.45% (6)
CJSIA	68	1004	282	28.09% (3)	2.66% (12)
CTTA	72	930	228	24.52% (6)	2.15% (15)
JCIC	202	4153	370	8.91% (15)	3.49% (11)
JDAP	82	1968	485	24.64% (5)	4.58% (8)
JEI	180	6721	1063	15.82% (11)	10.04% (3)
JEMI	112	1876	249	13.27% (14)	2.35% (14)
JIG	198	4221	3275	77.59% (1)	30.93% (1)
JRS	96	1474	384	26.05% (4)	3.63% (9)
PRAI	89	1890	685	36.24% (2)	6.47% (5)
SP	120	3943	686	17.40% (10)	6.48% (4)
Summary	**1939**	**44219**	**10588**	**23.94%**	

Figure 4. Depiction of SR and TR in Table 4



Detailed Statistics on Sub-Groups

The third statistic is a detailed classification of IE publications in each sub-group and for each journal. The results are listed in Table 5.

Many types of information could be obtained from Table 5; however, only four important observations are pointed out here:

1. From the number of publications in different sub-groups, it seems that image segmentation (A1), various processing techniques (P3) and image compression (P4) are the most important research topics in all these years. Compared to eight years ago, A1 is continuous rising; while P4 is continuous declining, just as predicted in (Zhang 2008b). Since there is no general theory on image segmentation, the research in this sub-group always attracts many attentions.
2. Listing the top ranking in each group could also reveal the current research focus. In IP, Ps and P4 are ranked in the top. In IA, except A1, A4 has also obtained a high score. These two sub-groups are closely related in the sense of object

Table 5. Detailed classification of publications in sub-groups

Journal	P1	P2	P3	P4	P5	P6	A1	A2	A3	A4	A5	U1	U2	U3	U4	U5	T1	T2	T3	T4	T5	T6	S1
AAS	30	——	33	15	23	13	63	12	10	72	61	46	28	6	17	16	4	2	16	5	3	18	1
AES	54	35	136	132	100	23	137	21	34	57	69	75	17	8	43	9	55	42	20	22	52	16	3
AGCS	32	——	12	6	5	1	17	9	12	18	——	46	5	3	——	——	2	——	——	——	89	11	1
CJBE	29	46	13	3	——	——	51	1	3	1	6	32	10	1	3	——	9	1	——	170	——	——	2
CJC	28	7	32	57	52	8	66	24	15	33	44	44	25	11	34	6	17	25	28	6	6	7	6
CJSIA	10	23	20	12	4	1	35	17	8	24	4	21	4	——	4	——	15	——	4	46	4	22	3
CTTA	29	114	7	——	——	2	14	3	——	1	——	6	1	——	——	——	9	——	1	13	——	27	1
JCIC	2	1	25	90	84	2	17	3	7	9	3	9	——	——	9	——	21	74	4	——	4	3	3
JDAP	24	6	48	43	18	9	54	9	15	27	41	26	3	1	13	5	42	24	15	15	26	20	1
JEI	105	10	114	106	76	26	94	8	25	86	61	78	12	1	22	2	35	35	9	7	134	15	2
JEMI	20	3	26	16	11	1	27	4	7	21	12	10	2	1	1	2	36	6	1	4	1	37	——
JIG	68	38	380	329	177	56	438	84	93	297	189	275	94	29	141	31	63	82	50	66	120	110	64
JRS	37	2	27	6	2	5	24	2	9	25	——	45	1	2	3	——	4	——	——	——	182	7	1
PRAI	12	5	26	12	13	2	123	28	22	84	114	47	19	13	43	10	1	1	79	9	4	15	3
SP	41	13	76	72	36	8	75	7	27	77	35	50	8	3	14	8	36	27	6	13	45	7	3
Summary	523	303	974	896	599	158	1238	233	287	832	643	810	231	79	347	90	347	313	233	376	671	315	90

detection with object model, the difference is that the former is more like an un-supervised task and the latter is more supervised. Some connections existed between the top one in IU, U1, and the top one in TA, T5. They are both related to remote sensing, as the former are more concentrated on theoretical aspects while the latter are more concentrated on application aspects

3. The detailed classification shows that different journals have a different emphasis, some of them cover all different sub-groups of IE (for example AES, CJC, JDAP, JEI, JIG, PRAI, and SP) more or less evenly, while some of them are more specialized in certain sub-groups of IE (for example, CJBE for T4, CTTA for P2, JCIC for P4, P5 and T2, and JRS for T5). That information would be useful for potential authors.
4. Finally, the summary in Table 4 is made for all eighteen years. However, some sub-groups have only been added to survey in recent years, along the techniques covered appearing with the evolution. Considering this factor, the average numbers of publications per year for different sub-group are supplied in a histogram form in Figure 5. Compared to Table 5, P5 and A5 provide another two promising recent research directions.

FUTURE RESEARCH DIRECTIONS

From a research point of view, it could be predicted that the IE research has a tendency and is going from low level to high level, that is, from image processing to image understanding, via image analysis. As shown in Figure 3, after a chaos in the beginning, Image Processing publications went to top in the early years, and now the Image Analysis overpasses it for several years. It is expected that more research and application needs would make Image Understanding goes up fast and fast.

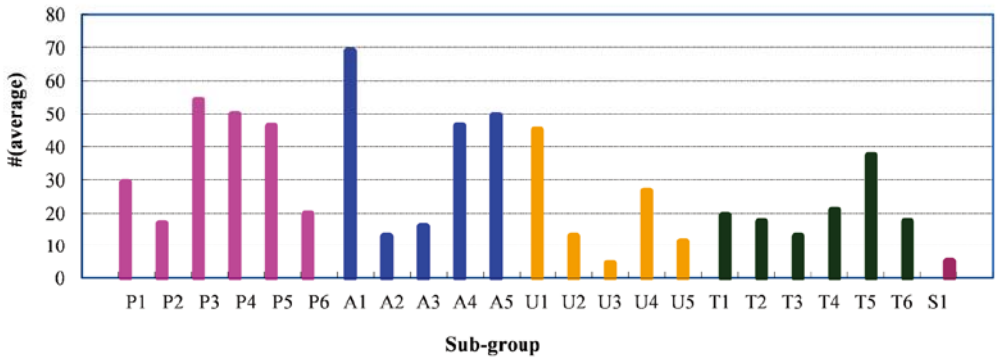
The field of IE has changed enormously in recent years. Many techniques have been developed, exploited or applied only in this century. It is seen that techniques for IE being implemented and used on a scale few would have predicted a few years ago. It is also likely that these techniques will find many new applications in the future.

Viewing the prospective of IE, the work for survey on IE could also be pushed deeply, at least, in two ways. First, since this survey provides an up-to-date picture regarding IE and its research advance, so further research could be advanced and promoted in appropriate directions. Second, according to the principles and methods of bibliometrics, a systematic investigation of the factors of the articles indexed in the survey series could be made.

CONCLUSION

This article shows an overview of a survey series on IE made in the last years. The idea behind and consideration on this survey, as well as a thorough summary of obtained statistics are illustrated and discussed. All these provide much of useful information regarding the tendency of fast progresses of IE in China and worldwide.

Figure 5. Numbers of publications per year for different sub-group



Such a work not only provides a convenient means for literature searching in IE, but also presents a detailed picture of hot research topics in the field. Moreover, it may be useful for publishers who want to quickly capture the general trends of development in IE, and for potential authors who wish to disseminate widely their research results in the associated communities.

ACKNOWLEDGMENT

This work has been supported by the National Natural Science Foundation under Grants NNSF-61171118 and the Ministry of Education under Grants SRFDP-20110002110057.

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KEY TERMS AND DEFINITIONS

Bibliometrics: Bibliometrics is a branch of science. It is a type of research method used in library and information science. It utilizes quantitative analysis and statistics to describe patterns of publication within a given field or body of literature.

Image: An entity that was captured by some visual systems in looking at the real world and that can be sensed to produce perception. It is a representation, likeness, or imitation of an object or thing, a vivid or graphic description, something introduced to represent something else.

Image Analysis (IA): One of three layers of image engineering, which is concerned with the extraction of information (by meaningful measurements with descriptive parameters) from an image (especially from interesting objects).

Image Engineering (IE): An integrated discipline/subject comprising the study of all the different branches of image and video techniques. As a general term for all image techniques, it could be considered as a broad subject encompassing mathematics, physics, biology, physiology, psychology, electrical engineering, computer science, automation, etc. Its advances are also closely related to the development of telecommunications, biomedical engineering, remote sensing, document processing, industrial applications, *etc.*

Image Processing (IP): One of three layers of image engineering, which encompasses processes whose inputs and outputs are both images, with outputs are improved version of inputs.

Image Techniques: A collection of various branches of techniques for processing (such as acquiring, capturing, sensing, storing, enhancing, filtering, debluring, inpainting, transforming, coding, transmitting, manipulating, *etc.*) analyzing (such as segmenting, representing, describing, featuring, measuring, classifying, recognizing), and understanding (such as modeling, registrating, matching, reconstructing, training, learning, reasoning, interpreting, *etc.*) images.

Image Understanding (IU): One of three layers of image engineering, which transforms data extracted from images into certain commonly understood descriptions, and makes subsequent decisions and actions according to the interpretation of the images.