A Critical Review of Machine Vision Applications in Construction

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Abstract -

Automation for retrieving relevant contents without human interventions has been considered as an essential task in the construction industry. Computer vision has grasped attention to be employed for providing rich data from the surrounding environment and automation of such critical tasks. Nonetheless, various challenges, including the detection of complicated and changing interactions and processing large-scale data remain unresolved. Deep learning methods have led to satisfactory achievement in providing progress monitoring systems, especially with detecting complex human motions and activities in construction scenes. However, further research contributions for vision-based safety monitoring are required to determine existing limitations and gaps in the construction and infrastructure field. In this paper, through some bibliographics and scientometrics analyses, more research backgrounds are suggested for application of computer vision and especially, deep learning, in construction robotics. Moreover, the accuracy of various computer vision methods is analyzed and compared by considering publishing year, countries, institutes. This demonstrates that Deep Learning application is still premature in the construction context, and current researches lack robust and swift image processing techniques.

Keywords -

Automation; Computer Vision; Construction; Deep Learning

1 Introduction

Automated methods have been considered as a vital task intended to retrieve relevant contents and features without any human interventions in the construction robotics [1]. In this regard, machine vision has drawn attention since several critical tasks, including continuous object recognition, monitoring of motion behaviour [2], productivity analysis [3], health and safety monitoring [4], require automation in their procedure [5] . It is worth noting that a major prerequisite for applying computer vision methods is data collection. Despite their importance, current methods of on-site data collection are still time-consuming, costly, and error-prone [6]. In addition, having large-scale database for most of industrial projects is another challenge for computer vision methods. In the recent years, several studies have been carried out in the construction field to evaluate unsafe conditions and acts. Despite the relative success of the research conducted by [7], some unresolved gaps and challenges remain in construction and infrastructure Civil Engineering, including the recognition of activities in complicated and varying conditions, multi-subject interactions and group activities.

Computer vision has achieved satisfactory performance in providing progress and quality monitoring systems and identifying unsafe conditions and actions in ongoing works, especially by detecting human motions and activities in construction sites [8, 9] In fact, color-based techniques such as the detection of workers, equipment, and materials in the construction sites are commonly used in various object detection [10] A behaviour based safety approach can be used to observe and identify people's unsafe actions in order to modify their future behaviour [11, 12] The advent of deep learning in machine learning field provides solution to the problems of manual observation of unsafe actions. The Convolutional Neural Network, CNN, based methods have been widely applied to a variety of problems that are encountered in construction [13, 14]. Object detection using deep learning algorithm can be employed for identifying construction components, counting objects, and objects size determination [15]. Furthermore, motion detection can be deployed in cameras via deep learning computer vision methods for surveillance purposes. In [16], a deep CNN is developed by integrating optical flow and gray stream CNNs to automatically recognize motion on construction sites.

By searching through the database of publications, 11 review articles are found which have put their effort on this area of interest, among which, from 2017, four papers have been published. This is important since what has developed from 2017 changes in data science interaction with construction and civil infrastructure fields. In Table 1, the information of the published review papers in this field has been demonstrated. From 2015 to 2016, five review articles have focused on this field of research, trying to provide bibliographic information,possible solutions and gaps on computer vision with share keys including progress monitoring, condition assessment, image-based 3D reconstruction, computer vision, and building information modeling;

Table 1. Analysis of published review papers on application of computer vision in the construction field.

Review Papers	Analyzing Date	Review Style	Reviewed Papered
[10]	2009-2019	bibliometric	97
[5]	1999-2019	scientometric	375
[19]	2000-2018	scientometric	216
[20]	1990-2018	bibliometric	235
[21]	2005-2016	scientometric	614
[22]	2010-2015	bibliometric	40
[6]	2000-2015	bibliometric	101
[23]	1995-2015	bibliometric	96
[24]	1995-2015	bibliometric	121
[25]	2005-2015	bibliometric	104
[26]	2000-2015	bibliometric	139

the most published articles belong to the journal of Advanced Engineering Informatics. Nonetheless, what has been considered has chiefly changed in recent years. As a case, one of the gaps in review papers was referred to the lack of suitable tool for processing and interpreting of high value of images and videos which was addressed in several articles, including [17, 18], by introducing deep learning methods in civil and infrastructure construction fields. It is worth mentioning that the relation between ontology and deep learning application in Civil Engineering has been analyzed in [19] which leads to suggestions for analyzing background detail and employing ontology in order to improve the accuracy of computer vision methods in monitoring and safety. Nonetheless, what has totally been off the topic in the scientometric analysis is the role of accuracy of different computer vision methods in the future of the construction field. None of the review papers has scrutinized and demonstrated the possible reasons and trends in the accuracy of computer vision methods from sceintometrical view point.

Therefore, further studies are required to find out existing limitations in order to boost the adoption of the advanced techniques. Several practical challenges could be identified in studies including a lack of robust and swift image processing techniques in industrial settings, considering the varying and dynamic conditions which are demonstrated in construction and civil infrastructure sites. Moreover, the review papers neglected the recent improvements and achievements in the general computer vision and machine vision. Hence, more researches are required for computer vision that involve the state-of-the-art deep learning findings in the construction field in order to provide the practitioners with more accuracy in identifying conditions resulting in inferior quality, productivity and safety performance. In this regard, using of a computational light convolutional network such as MobileNets [27], ShuffleNets [28], ResNets [29] seems necessary.

This research has tried to analyze this topic from different view point, that is more or less related to the data science field. In this paper, different methods of computer vision have been analyzed considering their application in the construction field. In Section 2, the way of acquiring bibliographical records of articles in the fields of machine vision and construction is explained. Thereafter, in Section 3 the recent achievements in the aforementioned fields are categorized and the most leading and cutting-edge articles in the field of application of computer vision in construction are extracted. Section 4 is devoted to the more detailed scientometrics analysis of the selected articles. Finally, discussions and future trends are included in Section 5.

2 Data acquisition

In this section, the method of acquiring bibliographical data is explained. In this research, the Dimension platform is employed as the basic search platform which offers more advantages[30, 31], such as proving plentiful research options, easily extracting research results, access to profiles at author and journal level, awarded grants and patents. In this regard, journals and conference papers are selected as the research option, since several highly cited documents have been published in both publication types. Moreover, the surveyed date has been set to 2000-2020 which contains the most published papers in the field of construction and machine vision. A suitable research keyword for application of machine vision in the construction and Civil Engineering might be as follows: ("Computer vision*" OR "Machine vision*" OR "Vision systems*") AND ("building*" OR "construction*"). Based upon the aforementioned settings for carrying out search in the platform, 2515 documents have been found for the rest of the research.

3 Bibliographical Analysis

In this section, the literature of computer vision application in construction is analyzed from bibliographical point of view. In this regard, VOSviewer software [32] possesses useful features in the text mining and bibliometrics analyses, which provides researchers with graphical way of literature data-set presentation. Considering the bibliographical results, demonstrated in Figure 1, four main clusters have been identified in the graph. The graph contains top 160 documents by total link strength. The first cluster, which has been demonstrated with yellow color, is mostly related to the articles belonging to implementation of conventional computer vision methods in construction. The leaders of the cluster [33, 9, 34, 16] share similar keywords, i.e., Support Vector Machine (SVM), computer vi-

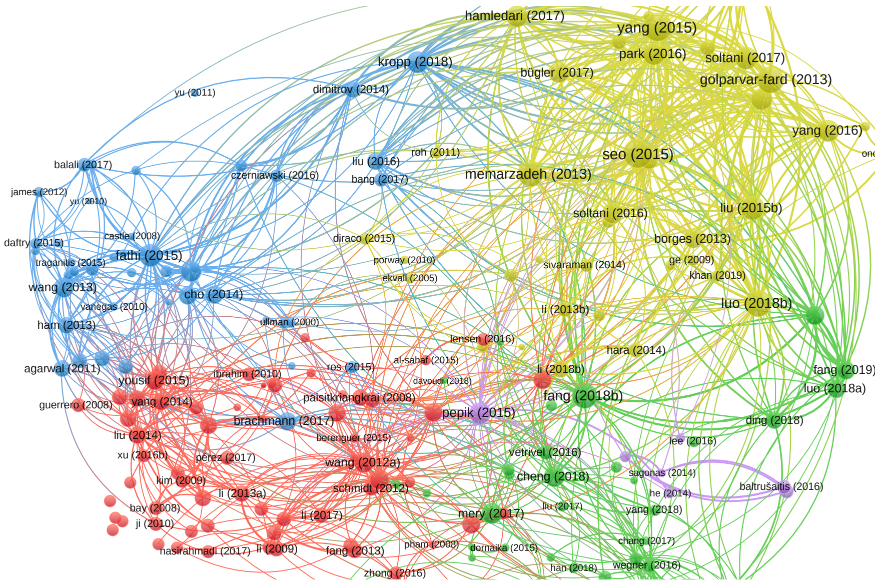

Figure 1. Network visualization of acquired bibliographic documents via bibliographic coupling analysis method.

sion and monitoring. The similar cluster with green color, #2, represents articles which has been published around 2017 in the application of deep learning in construction. The leaders of the cluster [35, 36, 37] share similar keywords, deep learning, computer vision, construction. In the scientometrics analysis, the articles of the cluster #1 and #2 are employed in order to analyze the connection between the keywords of those articles which forms better understanding of computer vision application construction and Civil Science. Therefore, the articles from clusters #1 and #2, with the number of 110, have been analyzed in the scientometrics section, from different aspects of scientometrics, especially accuracy of computer vision methods, data base, and co-occurrence. Nonetheless, there are two other main clusters that have been found in the bibliographical results in Dimensions search platform. One of these two clusters with red color, #3, has focused on the general computer science field with shared keywords, computer vision, classification, and object recognition, while the another with blue color, #4, has put the attention on Civil Engineer, 3D reconstruction, and building model. As a results, excluding these articles from main articles based on the titles and abstract in the bibliographics is impossible; only by employing methods such as the bibliographical coupling analysis, these clusters are separable. In the Scientometrics section, these two clusters are not analyzed since those are relatively far from the main topic of this research.

Based on the bibliographical data from Figure 2, the United States, China, United Kingdom, South Korea, Australia, and Canada have mainly attempted to contribute in

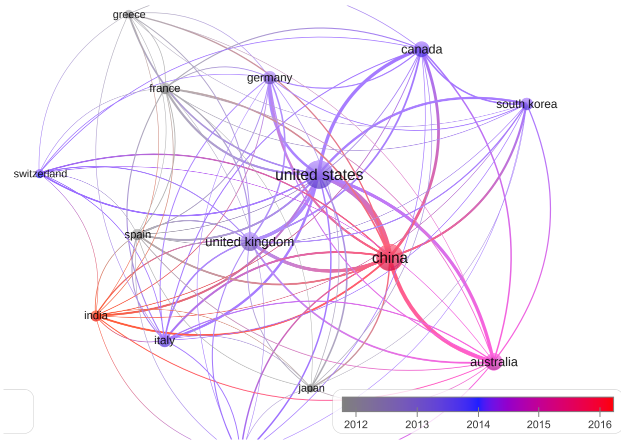

Figure 2. Overlay visualization of countries of published documents respecting to average publishing year via bibliographic coupling analysis.

construction and vision fields of researches. The graph nodes are scaled by total link strength in which minimum number of documents of a country is set as 20, minimum number of citation of a country is chosen as 10, and top 15 countries are visualized considering total link strength. Moreover, the graph demonstrates that from 2016 till now, China, Australia, and India have attempted to extend the application of computer vision in Civil Engineering. On the other hand, the focus of researchers in the United States and United kingdom is mostly respected to the span of 2012 to 2014 on average, and predicated upon the citation records, their researchers had received enormous attention and citation.

4 Scientometrics Analysis

In this section, the aforementioned extracted articles from clusters #1 and #2 of Figure 1 are analyzed through varied points of view. From 2015, a brand new way of literature review, namely, scientometrics analysis, , has been introduced [38] which detects the correlation between keywords and the most repetitive words through co-occurrence analysis. Consequently, by combining the bibliographical information of the selected articles with the extracted data such as accuracy, source of database, abstract and so forth, the scientometrics analysis has been carried out in this section in order to focus on surveying the published articles in the field of computer vision and construction. Employing corpus and scores files, composed by integrating abstract and keywords of the selected articles, the demonstrated graph in Figure 3 is obtained. The graph shows top 20 of most relevant and important terms scaled weight by Occurrence, with minimum number of occurrence of a term as 10. Based on the graph, Deep Learning as a representation for complex image processing methods and SVM as one for conventional image classification toolbox have been mentioned more than other methods.

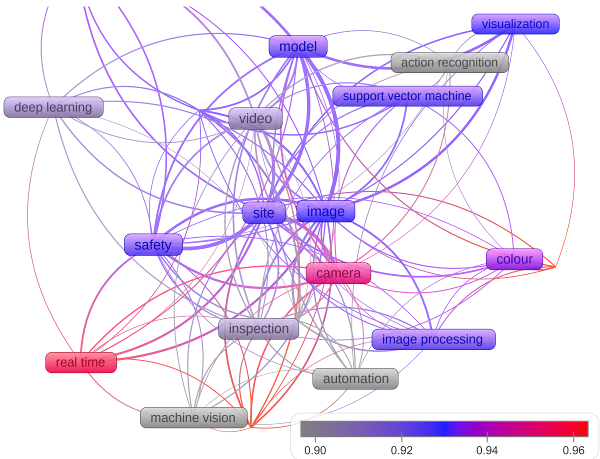

Figure 3. Overlay visualization of occurrence analysis of abstract and keywords of selected articles with respect to average accuracy timeline.

In the clusters #1 and #2 of Figure 1, representing fields of construction and machine vision, 3 publication journals have mostly contributed from volume of published papers point of view. In Table 2, several information have been presented on the publication resources, namely Automation in Construction, Advanced Informatics, Computing in Civil Engineering, and Computer-Aided Civil and Infrastructure Engineering and the corresponding details.

Table 2. Scientometrics analysis of the publication sources of selected articles.

Publication Journal	Percentage	Average Published Year	Average Citation	Dominant Method
Automation in Construction	37.04%	2016	91	Deep Learning
Advanced Engineering Informatics	14.81%	2013	92	Deep Learning
Journal of Computing in Civil Engineering	13.89%	2012	117	Edge Detection
Computer-Aided Civil and Infrastructure Engineering	8.35%	2012	193	Edge Detection

Table 3. Scientometrics analysis of the first author countries of selected articles.

Institution	Percentage	Average Published Year	Average Accuracy	Dominant Method
Huazhong University of Science and Technology	10.19%	2018	0.895	Deep Learning
Georgia Institute of Technology	12.04%	2012	0.938	Tracking Method
Yonsei University	6.48%	2014	0.967	Edge Detection
University of Illinois	9.26%	2011	0.982	Motion Detection

The focus of Automation in Construction and Advanced Informatics has been shifted toward applying deep learning methods in the construction field from 2016 [17, 35]. Nonetheless, the journal of Computing in Civil Engineering and Computer-Aided Civil and Infrastructure Engineering have published the articles, mostly employing edge detection methods, in the construction and civil engineering [39, 40].

From the countries point of view, the United States, China, Canada, the United Kingdom, and Australia are pioneers in applying computer vision in the construction field. In Table 3, it is shown that 4 institutions have had more contributions in publishing their results in the relevant journals. The average publishing year for Georgia Institution [8] and the University of Illinois [9] is around 2012; tracing methods and motion detection, respectively, are employed which have led to highly cited articles, but their focus has been shifted away from this field since

2014. On the other hand, several papers such as [41, 42] have been published from Huazhong University that contributes in this field by applying CNN and deep learning in the object and human recognition. These papers have been specialized in such a narrow topic that limits the citation while the average accuracy of the deep learning methods is less than the aforementioned institutions in the United States.

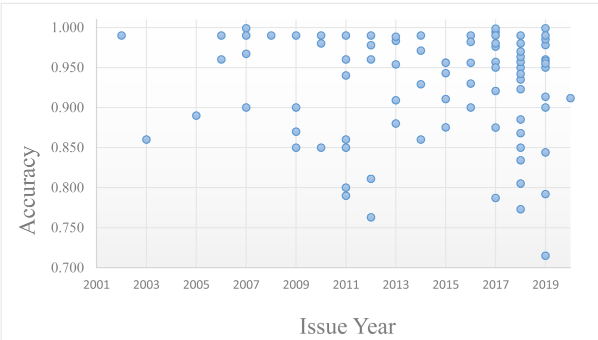

Figure 4. Scatter plot of the issue year of selected articles versus the accuracy of computer vision methods.

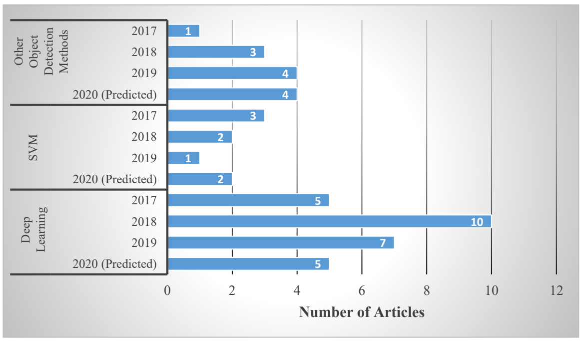

Figure 5. Comparing the applied dominant machine vision and classification methods in selected articles respecting to the issue year of articles.

Since 2008, by deployment of computer vision in the construction industry, the number of published papers in this field rouse by gaining appropriate accuracy of the object and edge detection methods. For instance, in Figure 4, one can observe that from 2008, more articles have achieved high accuracy in vision methods of construction mostly due to the advancement in face recognition and object detection methods. However, it is worth mentioning that one can find several articles including [41, 43] that cannot achieve expected accuracy, that is above 95 % on average, since the volume of processing data has increased as well. Consequently, in this field, the span of accuracy

Table 4. Scientometrics analysis of the dominant machine vision and classification methods in selected articles.

Method	Percentage	Average Published Year	Average Accuracy	Average Citation
Deep Learning	20.37%	2018	0.908	68
SVM	14.81%	2015	0.905	2120
Other Object Detection methods	12.04%	2015	0.955	49
Other Edge Detection methods	9.26%	2010	0.887	136

that publications in the construction field has gotten bigger whilst the bold part of this span is still on the highest possible accuracy of computer vision. Most importantly, the rate of published research paper in this field has accelerated since 2017. This has happened mostly due to attention that deep learning methods have received. Based on what has been demonstrated in Figure 5, since 2018, more research articles such as [44, 14] have put the base of their concentration on Deep Learning and big data science field. Face recognition, object detection, and huge amount of data classification methods are eventually possible to be carried out by deep learning methods. This trend decreased in 2019 which might be respected to the existing gaps of deep learning in the construction and safety field which will be discussed later in Section 5. Meanwhile, SVM method, which represents fast classification of data, fails to receive more credit in comparison to what has happened in 2015 [45, 46], according to Table 4. This shows that the focus of automation in construction has been shifted from speed toward the accuracy and processing of huge database information.

5 Discussion and Future Trends

In the recent years, the vision-based tasks have improved due to the need for automation in the construction field. Some of the researchers have tried to extend the volume of image processing, from motion and object detection tasks towards activity recognition. This has led to increasing complexity of the space of data regressors while the conventional methods lack the ability to conform to big data process. As a result, more complicated and powerful tools in learning patterns and data are required to solve the problem. However, based on what has been illustrated in Table 4, it is clear that deep learning methods could not achieved the accuracy that has been achieved in the

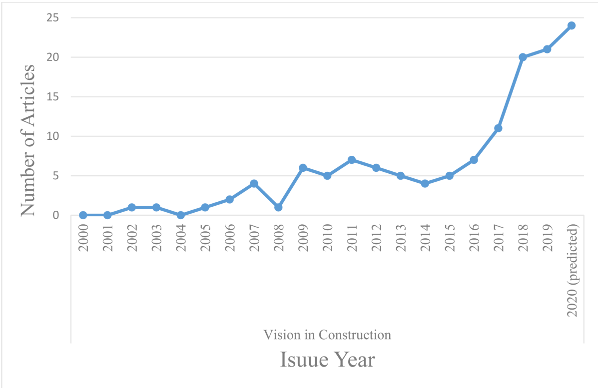

Figure 6. Number of published articles on the application of machine vision in construction respecting to the issue year.

vision field [18], that is approximately 95 %. Moreover, it is demonstrated that the achievement of conventional vision methods in the object detection, motion detection, classification reveals better accuracy in comparison to the deep learning methods [47]. The existing gap among the capabilities of deep learning in the construction field, employing pre-trained networks in non-similar contexts and lack of experience and background researches, decrease the possible success in obtaining successful results in the vision methods. In fact, setting AI field techniques such as MobileNets [27], ShuffleNets [28], ResNets [29] in construction and infrastructure civil field are demanding and time-consuming. Therefore, the upcoming articles must be inclined to increase the accuracy and efficiency of deep learning methods. By doing so, the predicted number of published articles on application of machine vision in construction, demonstrated in Figure 6, will be realizable.

Another important topic is the way of acquiring database for application of vision in construction industry. Most of researchers in this field have employed specific database. Based on the scientometrics data, the majority of the analyzed published documents in this field possess their own construction images database. Some of review papers, especially [19], believed that considering the copyright rules and respecting the privacy of workers in construction site often lead to the fact that most researchers do not publish their researches database in the publications. In this regard, there is rare published well-known database of construction images and the authors are obliged to put more of their effort and resources on acquiring images from a construction site. This may be the key point why researchers have put less effort and attention on improving the efficiency of computer vision methods, especially in deep learning-based recognition method, in the recent years. Furthermore, lacking general image databases in the construction field makes validation of the results in this field even harder. In other word, the precise comparison between application of varied machine learning methods in construction and infrastructure Civil Engineering is not mainly feasible since each articles applied the method on a specific database which is not accessible for other researchers and authors [17, 42]. In this regard, the average accuracy has been employed in this paper in spite of applying machine learning methods on each case study of construction field. As a future trend, a general database of construction sites must be formed respecting the privacy of involved people and the copyright rules, which surely involves more researchers in the applications of machine learning in the construction field.

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