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A computer approach to highlight unrecognized knowledge and technologies for designing safer and more reliable autonomous car system – exploring technologies for failure in different industries

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Development of an autonomous car is increasing and it is considered to be safer than a conventional car. To realize a reliable and fail-safe autonomous car system, it is important for the engineers of the system to assume exhaustively possible emergent situations that the system or the users of the system may face. And new knowledge not exist in a process of designing a conventional car system should be required in a process of designing an autonomous car system. To support such a situation of the engineers of the autonomous car, we propose a computer approach which structures patent information in a link-mining manner, create a map of technologies for various emergent situations that human can face, and highlight technologies which the engineers of the system may not have recognized yet but which can be possibly important to increase the reliability of the system.

1. Introduction

Un autonomous car is considered to be safer and more efficient in terms of traffic, fuel consumption, and driver's use of time, and is also expected to replace some duty such as freighter than the conventional car [1-2]. Preliminary Statement of Policy Concerning Automated Vehicles of National Highway Traffic Safety Administration [3] defined the levels of automation of a car (Table 1) in 2013. Many semi-autonomous technologies are already commercialized and appreciated as drive assist technologies. And major automobile manufactures continue their R&D efforts to advance the automation level. Mercedes unveiled a concept autonomous car, F015 Luxury in Motion, at the 2015 Consumer Electronics Show (CES) [4]. Audi invited several journalists on board of "Piloted Driving" from San Francisco to Las Vegas for the CES [5]. Bosch mentioned that it has already contracts of technology needed for highway assist system [6]. Such aa trend is not limited to the automobile manufactures and their suppliers. For example, Google has accumulated autonomous driving test more than 700,000 miles [7]. Many countries also support the advancement of the autonomous car technology. "Grand Challenge" organized by US Defence Advanced Research Projects, "Advanced Safety Vehicle (ASV)" promotion projects designed by Japan Ministry of Land, Infrastructure and Transport Study Group for Promotion of ASV, and City Mobil project, SARTRE of Framework Programs and Horizon 2020 of European Commission, are some example of country programs which have powered industrial and academic research on this domains.

Examples of technologies for an autonomous car are such as sensing the road condition, lane, the distance, speed and the size of other vehicles, pedestrians and other obstacles, planning the next motion and path, to control steering, throttle and brakes, communicating with driver, other vehicles and infrastructure, and integrating these technologies [8-9]. Many of these technology domains require new knowledge and approaches not exist in a process of designing a conventional car system.

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Table 1　Automation level and Example features [3]

Level	Example features
Level 0: No-Automation	forward collision warning, lane departure warning, blind spot monitoring
Level 1: Function-specific Automation	cruise control, automatic braking, and lane keeping
Level 2: Combination Function Automation	adaptive cruise control in combination with lane centering
Level 3: Limited Self-Driving Automation	automated parking
Level 4: Full Self-Driving Automation	N/A

And obviously, reliability in both technological and social terms is the most important factor for the successful introduction of the autonomous car to the market. Various emergent situations could be happened to an autonomous car such as system failure, driver's health problem, and unexpected road condition with bad weather. How can the driver take over the control of the car immediately when the autonomous car system went wrong suddenly? How should the car and the drivers of other cars around do when a driver passes out? Can we really sure that the sensors work always perfectly? There are also active discussion about who should take the liability in case of accidents and which liability system can motivate stakeholders to pay favorable attentions for safe operation of the autonomous car [9]. Some also warned that coexistence of autonomous car and conventional car would be very dangerous [10].

On the other hand, research on a computer-based citation analysis method, which can structure large scale of data such as patents and academic papers based on the citation information data and create the overview of data, is active in the Information Science. Researchers and decision-makers related to science and innovation management evaluate citation analysis approaches as quantifiable and objective approaches that can compensate and validate the experts' judgments [11-12], and can be used in administration fields (see [13]). Furthermore, innovation is recombination of knowledge so that enabling breadth search or learning from different knowledge domains is expected to increase the possibility of radical innovation [14-17]. We consider such an approach can contribute toward development of an autonomous car system.

Previously, using a computer-based citation analysis approach, we proposed and showed the effectiveness of "Recognized-Unrecognized matrix" to make people embedded in the local context aware global issue [18]. We compared two set of academic articles discussing sustainability globally and locally. Here we chose the aviation industry as local. The overview created from the academic articles not limited to the local articles enabled people of the aviation industry to discuss a potential issue which is not yet recognized locally but can become an issue one day. This research can be extended to search potential emergent situations for an autonomous car system. We consider that, for a reliable and fail-safe design, it is very important for the engineers to assume possible emergent situations exhaustively in the design phase. On the other hand, adopting the citation analysis approach to structure patent data, we discussed "DB-C combination model" that considers three different knowledge combinations in depth (D) and breadth (B) based on similarities of two technological knowledge domains and found a citation analysis method with text similarity measurement has "the potential of measuring 'DB-C combination' that are pairs of technology sub-domains with weak similarity that may bring a technological breakthrough [19]. This research can be extended to seek useful technologies for an autonomous car system development. As we mentioned already, new knowledge and approach are required for the engineers of a conventional car at the development of an autonomous car system.

In this paper and another paper at the same meeting for the Intelligent Computer System Special Interest Group (in Japanese, [21]), we extended our previous researches in order to contribute toward the development of an autonomous car system. We would like to help the engineers to explore various emergent situations and recognize technologies of other domains which can be possibly useful to the increase of the reliability of a system. The first part, to explore various emergent situations and to compare them with current autonomous car technology roadmaps will be discussed by Osawa and Nakamura [20]. In this paper, we discuss the latter part, to highlight possibly useful technologies for a reliable and fail-safe autonomous car system.

2. Methodologies

2.1 Data

In order to investigate the possibly useful technologies in breadth for the development of a reliable and fail-safe autonomous car system, we collected two set of patent data; one is patents which include at least one word of fail* (* is wild card) in the text such as the title and abstract and another is patents which were searched with a queries used at the report by JPO (Please see [8]). The first dataset is assumed at this paper as the set of technology information about failure and the latter dataset is as the set of technology information about an autonomous car.

We use the Thomson Innovation provided by Thomson Reuters to collect patent data, because Thomson Innovation is a comprehensive worldwide patent database system, which covers patents recorded at more than 80 patent authorities and includes USPTO, the World Intellectual Property Organization (WIPO) (DWIP from 1978), the European Patent Office (EPO), and the Japanese Patent Office (JPO). Thomson Innovation also offers Derwent World Patents Index (DWPI) patent data and the Derwent Patent Citation Index (DPCI). We used the DWPI and DPCI to collect data on patent families and citations. While the claim of priority or disclosure as a member of a certain patent family is not mandatory, DWPI defines a family based not only on claim, but also on the investigation of experts. The DWPI bundles patents recorded at 47 worldwide patent authorities as a protection for the same invention as a sort of family. DWPI defines the new invention as a basic patent and adds information about patents for the same invention issued in other countries as equivalents, but in this paper, we call a basic patent a parent patent and its equivalent, a child patent. DWPI also provides manually added English abstracts from patent documents issued in more than 30 foreign languages so that it can allow text analysis of inventions from non-English language sources.

289,289 for the failure technology were retrieved at January 2015 and 67,083 patents for the autonomous car technology were retrieved at April 2015. Obviously, it is difficult to consult such a large number of patents manually.

2.2 Citation Analysis Method for Structuring Patent Data

In order to create the overview of technologies of patents, the patent data are converted into a non-weighted, non-directed network in which a patent is represented as a node and backward citations to patents as links. We created links among DWPI parent patents by utilizing DPCI citation information. Here we skip the explanation of the detail but use of DPCI citation information enable to find a link between DWPI parent patents which don't cite each other directly but which are linked with through a citation between family members of the patents (Please see [21]). The maximum connected component (MC) of the network is extracted. To minimize noise data and the quantity of data, we regarded patents not citing or cited by other patents in the component as digressional from the mainstream of those technological domains and eliminated them. The MC was divided into clusters depending on the density of links using a topological clustering method [22-23]. After clustering the network, we characterize each cluster by the expert-based approach and use the result as the overview of technology. Fig 1 is the schematic image of our research.

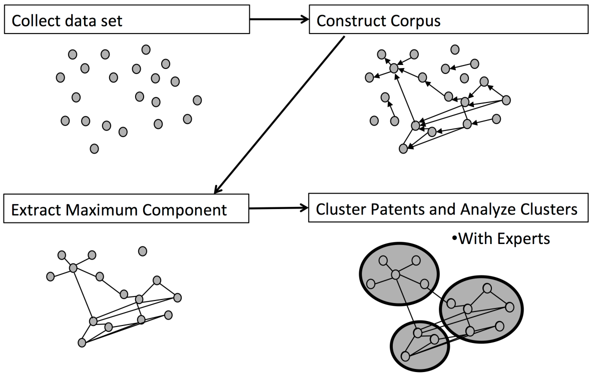

Figure 1. Schematic diagram of the citation network analysis

2.3 Similarity Measurement

We measure the possibility of transferring knowledge between different technology domains using cosine text similarity measurements, assuming that the similarity in characteristics such as background problems, processes to solve the problem, operational conditions, or compounds, can be measured by similarity in the text.

First, the DWPI title and abstract of each text were analyzed and the frequency of word i in Cluster s ($FreW_{si}$) was evaluated by the following formula:

$$FreW_{si} = \frac{n_{si}}{n_s} \times \log\left(\frac{N}{N_i}\right) \quad (1)$$

In (1), n_{si} represents the number of word i that appeared in the DWPI title and the abstract of the patents of Cluster s obtained in citation analysis. n_s represents the number of words that appeared in the title and the abstract of patents of Cluster s. N is the number of clusters in total. N_i is the number of clusters in which a patent contains the word i in the title and the abstract. The similarity of the text is evaluated by a cosine similarity that is often used in text mining and regards each text as a vector with the length of $FreW_{si}$. Cosine similarity *cos(a,m)* between two clusters a and m is defined as (2). A large *cos(a,m)* represents a relatively high similarity.

$$similarity = \cos(a,m) = \frac{\sum FreW_{ai} \times FreW_{mi}}{\sqrt{(FreW_{ai})^2}\sqrt{(FreW_{mi})^2}} \quad (2)$$

3. Results

We obtained the MC of 67,517 with the average application year of 2002.0 from the failure technology patent dataset and the MC of 43,041 with the average application year of 2003.5 from the autonomous car technology patent dataset. The MC of two dataset were clustered into 693 and 467 clusters. The clustering results are visualized as Fig. 2 and Fig. 3. For the visualization of the clustered network, we used a large graph layout (LGL) [24]. LGL is based on a spring layout algorithm where links play the role of spring connecting nodes. As a result of this layout a group of patents citing each other is located in closer positions. In our visualization we hide inter-cluster links and only show the intra-cluster links for each cluster with the same color to clarify the position of each cluster. We highlighted the major clusters by a white loop and noted the number of patents in a cluster, average of the application year of patents in the cluster and the title named by the authors manually based on the core patents.

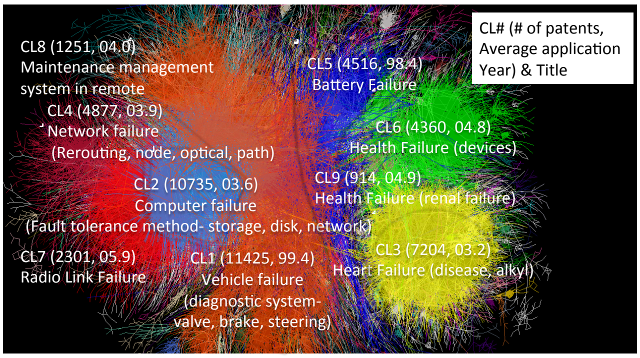

Figure 2. Overview of the Failure Technology

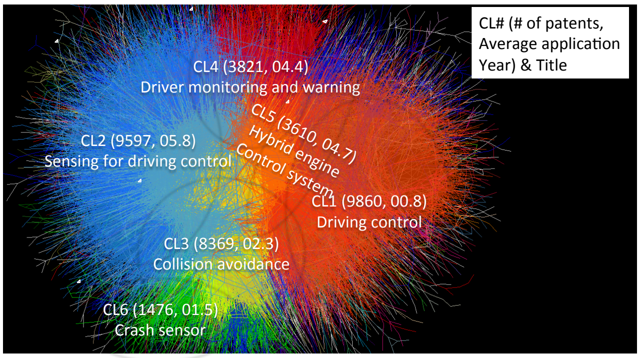

Figure 3. Overview of the Autonomous Car Technology

Table 2. The result of the cosine similarity measurements between major clusters of the Failure technologies and the Autonomous car technologies

		Failure Technologies								
Car Autonomous		1	2	3	4	5	6	7	8	9
	1	0.3833	0	0	0.0261	0.0091	0	0	0	0
	2	0.0232	0	0	0	0	0	0	0.1047	0
	3	0.1141	0.0305	0	0.0124	0.0134	0	0	0.0172	0
	4	0.1548	0.031	0	0.0192	0	0	0.0362	0.1625	0
	5	0.2129	0.0346	0	0.097	0.0912	0	0.0394	0.1839	0
	6	0.0501	0	0	0.0219	0	0	0	0	0

Table 2 is the result of the cosine similarity measurements between major clusters of the failure technologies and the autonomous car technologies. You can see that there are little similarity between the major clusters of the autonomous car technology and clusters CL3, 6 and 9 of the failure technology, which are group of patents on human health failure. CL3 is a group of patents for treating diseases such as hypertension and heart failure, CL6 is for medical devices for heart failure, and CL9 is for evaluating renal disorder. We also measured the similarities between major clusters of the failure technologies and the sub-clusters of CL1, 2 and 3 of the autonomous car technologies. Sub-clusters are obtained by repeating the clustering method to the patents of each cluster.

4. Discussion

Here is the example of pairs of clusters of the failure technologies and the autonomous car technologies with relatively high cosine similarity. According to our previous research, a cluster pair with relatively high cosine similarity may have a potential of knowledge transferring.

- Failure CL1: Vehicle failure such as a diagnostic system for valve, brake and steering
  - Autonomous CL1-1: Transmission system
  - Autonomous CL1-3: Speed control system
  - Autonomous CL1-5: Hybrid drive system
  - Autonomous CL1-11: Electrically controlled safety brake system
- Failure CL2: Computer failure such as fault tolerance methods
  - Autonomous CL1-4: Drive control system using maps
  - Autonomous CL3-4: Systems for preventing a collision
- Failure CL4: Network failure such as rerouting
  - Autonomous CL2-7: Informing to drivers and decision making about the distance to the other cars and timing to brake
  - Autonomous CL3-4: Systems for preventing a collision
- Failure CL5: Battery Failure
  - Autonomous CL1-5: Hybrid drive system
  - Autonomous CL2-7: Informing to drivers and decision making about the distance to the other cars and timing to brake
- Failure CL6: Medical devices for heart failure
  - Autonomous CL3-26: Vibration for alerting the driver and analyzing driver's state
- Failure CL7: Radio link failure
  - Autonomous CL3-4: Systems for preventing a collision
  - Autonomous CL17: Internal communication and vehicle to vehicle communication
- Failure CL8: Maintenance management system in remote
  - Autonomous CL1-4: Drive control system using maps
  - Autonomous CL2-1: Systems to measure the risk and prevent a collision by sensing external environment
  - Autonomous CL2-7: Informing to drivers and decision making about the distance to the other cars and timing to brake
  - Autonomous CL3-4: Systems for preventing a collision
  - Autonomous CL5: Hybrid engine control system
- Failure CL9: Medical devices for evaluating renal disorder
  - CL2-20: Sensors such as visual sensor for monitoring obstacles

The relations between highlighted pairs are not difficult to imagine. For example, to design a drive control system or navigation system using map information (CL1-4, a sub cluster of CL1 of the Autonomous car technology), it is clearly important to consider the situation of failure of a computer-based control system (CL2 of the Failure technology) and should be useful to know what kind of fault tolerance methods for computer exists. Another example is about CL8 of the Failure technology. For various computer-based systems in the autonomous car (CL1-4, CL2-1, CL3-4, CL5) will be benefitted by some remote maintenance management systems (CL8 of the Failure technology). A service provider can check the condition of systems mounted in an autonomous car.

To evaluate the contribution of our research, we would like to discuss whether our semi-automatic approach to identify cluster of technologies and to highlight possible pairs of knowledge combination, where putting thresholds to highlight and characterizing each clusters were conducted manually, effectively highlighted some knowledge that were not recognized locally, that is, by the engineers of the autonomous car but potentially important for them.

We firstly investigated how many patents are both in the dataset for the failure and for the autonomous and found that only 1,317 patents among 355,055 patents are common in the two patent dataset. Therefore, the overview of the failure technology is mostly the overview of not an autonomous car technology. However, as we used very rough query for gathering failure technologies and very precise query for the autonomous car technologies, there could be more common patents between the two dataset if we use different queries for the autonomous car, for example.

To know whether the engineers of the autonomous car are familiar with the technology of other domains, it would be also useful to consider whether their companies have patents in the other domains. As a new knowledge and approach should be required to the conventional car engineers, if our approach highlights cluster of different companies, it may enable the autonomous car engineers to recognize a new technology and approach. In the MC of the failure technology, excluding 7,835 of patents which don't have an information of applicant, 36,981 are patents of companies not applied a patent categorized in the MC of the autonomous car. Table 3 shows the number of patents in a cluster of the failure technology applied by a company not appeared in the paired cluster of the autonomous car technology. Here, it is difficult to count numbers of patents of a company exactly because the name of companies appeared in a patent document are not standardized yet (Toshiba can be discribed as "Kabushiki Kaisha Toshiba", "Toshiba Corp.", or "Toshiba Corporation".). We considered such a variation of names but we must note that the results are still rough and not a precise. Table 3 shows that our approach highlighted clusters of the failure technology with many patents of companies different to the companies applied patents which are categorized into the highlighted autonomous car clusters.

To evaluate our research more comprehensively, we must discuss whether

A) The similarity of the two clusters highlighted in this paper is already recognized and the transfer of knowledge in on the way. They have a partnership with the companies of the failure technology clusters.

Autonomous		CL1−1	CL1−3	CL1−4	CL1−5	CL1−11
Size		2718	2093	1093	909	65
Failure CL 1	Cosine	0.2913	0.2885	0.0987	0.2427	0.3683
(Size) 11425	#	6838	6680		7344	8695
	Example	IBM, GE, Toshiba	IBM, Toshiba, Boeing		IBM, Toshiba, Boeing	IBM, GE, Toshiba
Failure CL 2	Cosine	0	0	0.0312	0	0.0127
10735	#			8147		
	Example			IBM, Microsoft, EMC		
Failure CL 4	Cosine	0.0329	0.021	0.0239	0.0186	0
4877	#					
	Example					
Failure CL 5	Cosine	0	0.0236	0	0.0946	0
4516	#				3600	
	Example				IBM, Toshiba, American Power	
Failure CL 6	Cosine	0	0	0	0	0
4360	#					
	Example					
Failure CL 7	Cosine	0	0	0	0	0
2301	#					
	Example					
Failure CL 8	Cosine	0	0	0.0176	0	0
1251	#			820		
	Example			NEC, IBM, Canon		
Failure CL 9	Cosine	0	0	0	0	0
914	#					
	Example					

(continuted)

Autonomous		CL2−1	CL2−7	CL2−20	CL3−4	CL3−26	CL5	CL17
Size		2206	279	14	1299	3	3610	178
Failure CL 1	Cosine	0	0.0234	0	0.0481	0.0125	0.2129	0
(Size) 11425	#							
	Example							
Failure CL 2	Cosine	0	0	0	0.0568	0	0.0346	0.0588
10735	#				5903			
	Example				Microsoft, EMC, NEC			
Failure CL 4	Cosine	0.0532	0.0703	0.0585	0.0841	0	0.097	0.1571
4877	#		3522		2985			
	Example		Cisco, NEC, ZTE		ZTE, NTT, NEC			
Failure CL 5	Cosine	0	0.0788	0	0.0095	0	0.0912	0.0396
4516	#		3648					
	Example		GE, Siemens, American Power					
Failure CL 6	Cosine	0	0	0.0437	0	0.0626	0	0
4360	#					4360		
	Example					Cardiac, Medtronic, Pacesetter		
Failure CL 7	Cosine	0.043	0.0425	0.0214	0.0704	0	0.0394	0.2348
2301	#				1480			1942
	Example				ZTE, LG, Huawei			ZTE, Samsung, Qualcom
Failure CL 8	Cosine	0.243	0.2282	0	0.1485	0	0.1839	0.0143
1251	#	444	769		823		847	
	Example	Canon, Fuji Xerox, Nomura Research	NEC, Canon, NTT		NEC, Canon, NTT		Hitachi, IBM, Canon	
Failure CL 9	Cosine	0	0	0.0241	0	0	0	0
914	#			914				
	Example			Astute, Abbott, Amgen				

#: Number of Patents of different applicant in the Failure CL (It is only a rough idea because of lack of standard on the notation of the company name)
Example: Example of applicants of patents in the failure cluster which are not appeared in the applicants of patents of the autonomous cluster

Table 3. Cosine similarity results, number of patents of different companies in the failure cluster, example of the different companies in the failure cluster

B) There are few of opportunity of transferring technologies between the two clusters highlighted in this paper. Even though the highlighted pairs have some commonality in notion, the autonomous car technology should require very different technologies.
C) There are existing technologies of different domains that engineers of an autonomous car can further investigate and transfer to their areas.

Whether a pair is A), B) or C) can be concluded only by consulting the experts of the autonomous car. We are planning to have such a interviews in the near feature.

5. Concluding Remarks

We have discussed an application of a computational citation analysis approach to support engineers of an autonomous car to conduct comprehensive design process for a reliable and fail-safe autonomous car system. We have provided an overview of various failure technologies not limited to the car industry and tried to highlight potentially transferable knowledge. We highlighted some failure technology domains, whose relationship with an autonomous car system is not deniable and which includes not a few of patents applied by different companies to companies applying patents of highlighted autonomous car technology domains. The real contribution of our approach will be tested through experts interviews planned in the next research.

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