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# The railway catenary condition monitoring: a systematic mapping study of recent research

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## Abstract

In this paper, the systematic mapping method is applied to the literature of the past five years which summarizes three different facets of railway catenary monitoring. This systematic mapping can provide a clear overview of specific trends and current status in condition monitoring of railway catenary systems and guide new research on this topic in the most efficient manner.

**Keywords:** systematic mapping, railway catenary system, condition monitoring

## 1 Introduction

In the electrified railway system, the locomotive and multiple units collect current through the pantograph from the catenary system, to power the train. The catenary system is therefore a key part to ensure the efficient operability and reliability of the whole railway system [1][2][3][4]. Failures or defects in the catenary system may cause considerable delays or even safety issues [5]. Thus, to enhance the operability and reliability, condition monitoring for the catenary system has drawn much attention from researchers in recent years, a large quantity of research has focused on it. In this paper, a systematic mapping of the research in recent five years of catenary monitoring will be presented. Systematic mapping is the methodology to provide a structure of the type of research reports and results in a certain field that have been published by categorizing them and visualizing them in the form of a map [6]. The purpose of this work is to provide a clear overview of specific trends and current status in condition monitoring of railway catenary systems and guide new research on this topic in the most efficient manner.

For catenary monitoring, there can be different faucets. Firstly, there can be different types of monitoring targets, such as contact force between the catenary and pantograph, the arc, the catenary components (e.g. insulator, dropper, and so forth), etc. Secondly, different types of sensors are utilized for the monitoring such as camera, accelerometer, etc. Lastly, the platform to install those sensors varies. The platform can be normal-vehicle based, dedicated-vehicle based, or non-vehicle based.

Various facets may bring in difficulties to review work, however, systematic mapping can handle different facets well. It provides a more coarse-grained overview with less effort compared to systematic review [6]. The systematic mapping can conclude different facets in a field well, because the map normally has different axes representing the facets. The relationships between different faucets can be revealed through the map. So, the systematic mapping can provide a clear overview of a specific research field and the inner correlation of various aspects inside it. The map is presented in the last two sections.

# 2 Methods

The detailed procedure for systematic mapping is outlined in references [6][7]. Briefly, it can be described in figure 1 below.

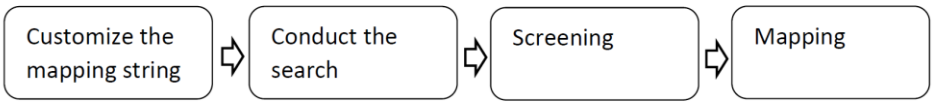


Figure 1: The process of systematic mapping

The first step is to construct the search string. The way used in this paper is modified from study [8]. It is constructed by the Boolean operators to describe the search target. Our focus is “the condition monitoring of the railway catenary system”. So, firstly this sentence can be decomposed into three keywords “condition monitoring”, “catenary”, and “railway”. There would be synonyms for those keywords as shown in table 1.

| **Keyword 1** | **Keyword 2** | **Keyword 3** |
|---|---|---|
| catenary<br>overhead contact line<br>overhead line<br>contact wire | condition monitoring<br>monitoring | railway<br>rail |

Table 1: the keywords in the search string

Considering those synonyms, the search string finally is:

**(catenary OR overhead contact line OR contact line OR contact wire) AND (condition monitoring OR monitoring) AND (railway OR rail)**

The search was carried out in December 2021 and only the papers published from 2017 to 2021 are included. The search results and corresponding databases are shown in Table 2.

| **Database** | **Search results** |
|---|---|
| ScienceDirect | 177 |
| Web of Science | 72 |
| Engineering Village | 73 |
| Scopus | 83 |
| IEEE | 47 |

Table 2: The search results

After the search, the screening would be applied to the results. The criteria for the screening are:

- Written in English.
- Full-text is available online.
- The content should directly be about the condition monitoring of the catenary system.

The first two criteria are easy to apply. For the third one, the abstract is utilized to determine the content, if it is hard to deduce the content from it, the introduction or the conclusion part would be read. After the screening, there are 70 papers in total meeting the requirements.

# 3 Results

The mapping process would be carried out after the screening. As mentioned in the introduction section, there are different facets in the field of catenary monitoring, in this paper, three facets are defined shown in table 3. The reason to choose these three facets is that they are the most fundamental facets in condition monitoring and they are the research focus in recent years and there might be correlations among them. Figure 2 to figure 4 shows the contribution of each item in their facet respectively.

| Facet 1 monitoring targets | Facet 2 sensor types | Facet 3 monitoring platform |
|---|---|---|
| contact point | camera | normal-vehicle -based |
| wear | FBG (fiber bragg grating) | dedicated-vehicle-based |
| contact force | ultrasonic | non-vehicle-based |
| arc | accelerometer | |
| components | radio receiver | |
| temperature | thermal camera | |
| tension force | | |
| catenary uplift | | |

Table 3: Different facets in this study

As shown in figure 2, the most popular detection target in recent five years is the catenary components such as insulator, dropper such as paper [9][10]. This might be because the development of computer vision techniques in recent years makes vision-based detection promising and so attracts the researchers' focus. And the component monitoring previously relies on manual inspection which is highly labor-intensive. Besides the monitoring, the contact-related targets such as contact point, contact force, arc, wear also account for a large proportion, since the contact quality is significant for the operability of the railway system.

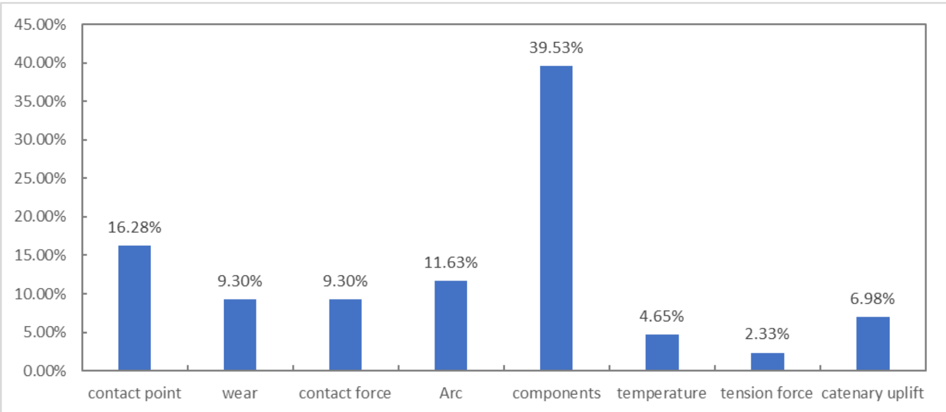


Figure 2: Different monitoring targets

In figure 3, among various sensor types, the camera has a distinct dominance over other types of sensors in recent five years. For example, Zhang et al. [11] utilizes a set of global shutter cameras to detect the contact point in complex background. This is again due to the fast development of the vision-based monitoring techniques in recent years. Figure 4 shows the monitoring system based on normal vehicle outweigh other platforms, this reveals a trend that normal-vehicle-based monitoring system is of more interest for that it can provide more frequent inspection than other types. The normal-vehicle-based monitoring can be found in [12][13].

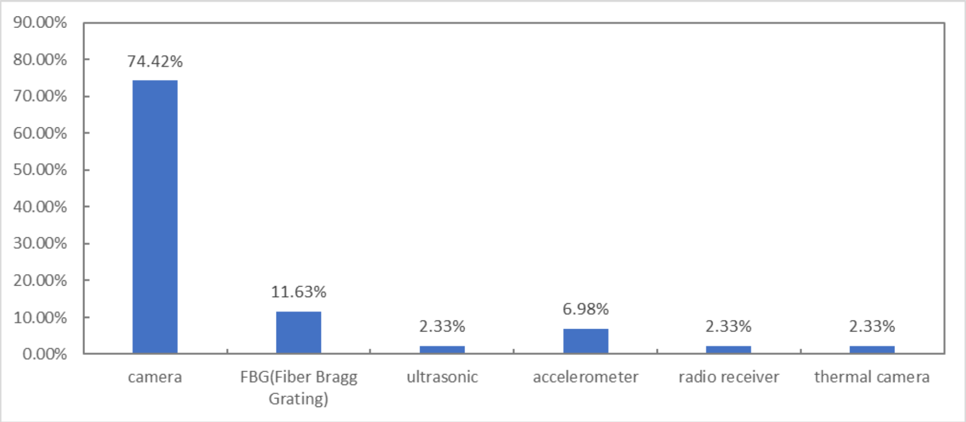


Figure 3: Different sensor types

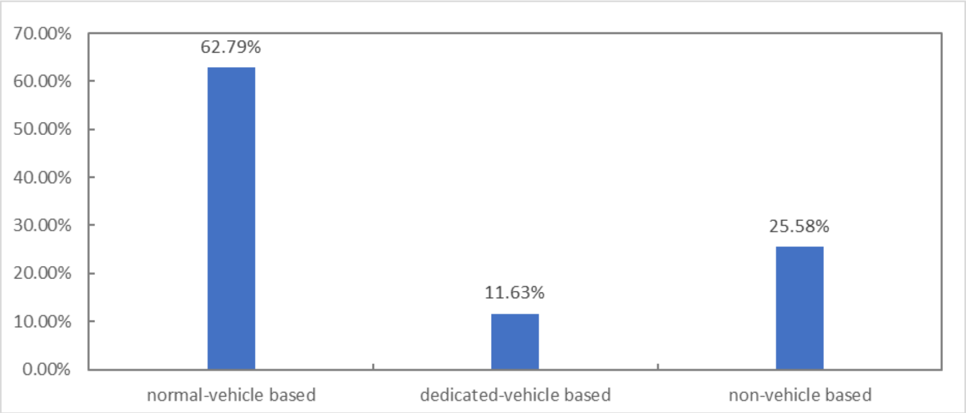


Figure 4: Different platforms

## 4 Conclusions and Contributions

The discussion in the "result" section focuses on each facet individually, but it is worth discussing the correlation inside among facets. So, besides the systematic mapping results in the previous section, in this section, the correlation between monitoring targets and sensor types and correlation between monitoring targets and platforms would be investigated respectively in a form of the bubble map. Figure 5 shows the correlations.

As shown in the right part of the plot, the biggest bubble comes from the intersection of the camera sensor and catenary component monitoring, and the next comes from the camera sensors and contact point monitoring. This fact indicates the catenary component and contact monitoring relies on computer vision techniques, for example, work [14][15]. In terms of the left part of the plot, it is shown that these monitoring targets have different distributions regarding the platforms. For catenary components detection, it has an even distribution for these three platforms, and for contact-related targets monitoring, they have bigger reliance on the normal-vehicle-based platform.

Overall, it can be seen that the camera is the most popular sensor type and can be used for monitoring various targets and the platform to install the camera is mostly the normal vehicle, which are also shown in the case in [16][17].

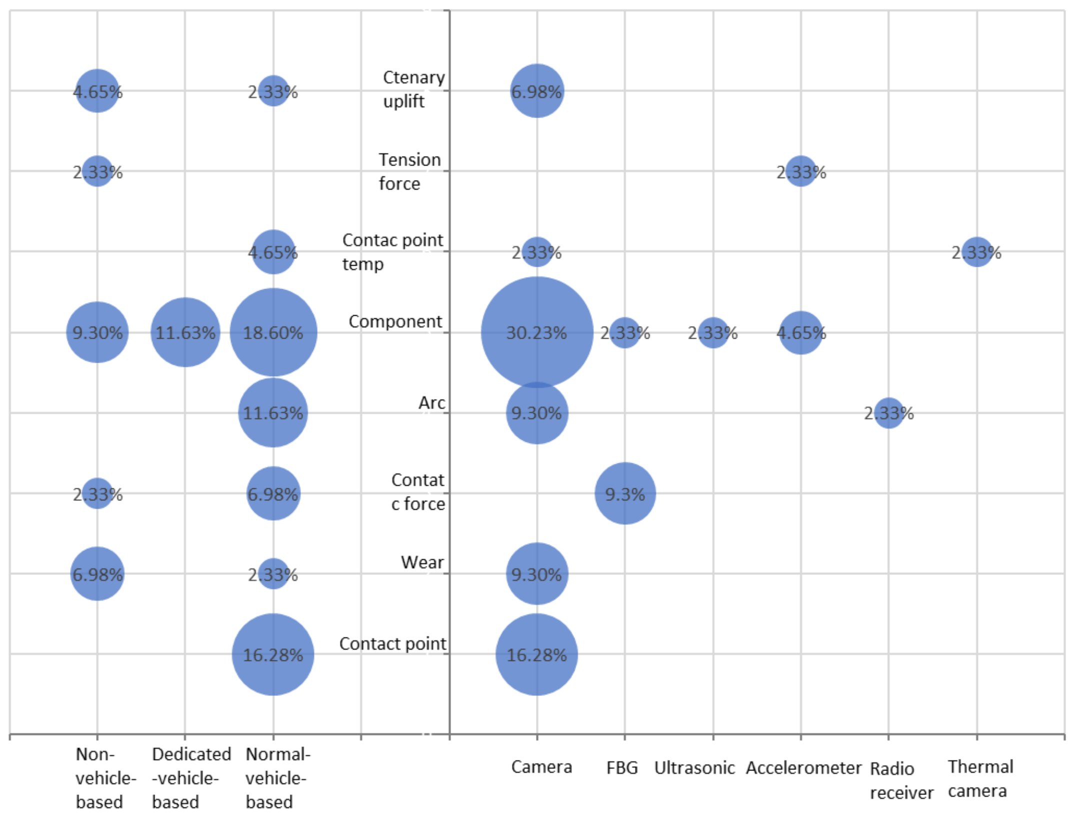


Figure 5: Bubble plot in relation to monitoring targets and sensor types and in relation to monitoring targets and platforms respectively

From all the analysis in this paper, we can conclude that due to the recent fast development of computer vision techniques, the vision-based monitoring has gained large popularity, and so the camera sensor is the most commonly used sensor type in recent research which can be used for component, arc, contact point monitoring, etc. And installing the sensors on the normal-in-service train is a common solution scheme, which can give a more frequent and more-covered monitoring to the targets.

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