# A Text Mining Analysis of Digital Twins for HRI

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## ABSTRACT

The interest for digital twins has kept rising over the recent years. With potential applications in different sectors, digital twins, like other robotic and autonomous systems, will have to interact with humans and in many cases collaborate with them. The present paper is a work in progress and applies text mining techniques to explore the use of digital twins for human-robot interaction scenarios.

## KEYWORDS

Digital twins, human-robot interaction, text mining.

**ACM Reference Format:**
Fanta Camara. 2023. A Text Mining Analysis of Digital Twins for HRI. In *5th VAM-HRI Workshop, ACM/IEEE International Conference on Human-Robot Interaction, March 13-17 2023, Stockholm, Sweden.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/1122445.1122456

## 1 INTRODUCTION

Despite the growing interest for digital twins, finding a standard definition remains a challenge. For example, Semeraro et al recently reviewed several definitions with a focus on smart manufacturing [8]. But more generally, Walker et al. describe a digital twin as "a virtual replica or representation of a real object or robot" [9]. Digital twins thus aim to replicate physical objects, enable to monitor and control them from afar.

Nowadays there are numerous attempts to make these digital twins collaborate directly with human operators or co-workers. To explore this research area, we collected some data and applied text mining techniques (topic modelling, clustering and sentiment analysis) to explore the trends, applications and sentiments towards digital twins for human-robot interaction (HRI).

## 2 DATA COLLECTION

We collected data through Google Scholar using the following keywords "digital twins human-robot interaction" and "digital twins human-robot collaboration". This gave 5,580 results compared to 378,000 results for the keyword 'digital twins' only. This big difference in the search results quickly highlights that the human interaction aspect is currently an under-explored research area.


*VAM-HRI 2023, March 13-16 2023, Stockholm, Sweden*

ACM ISBN 978-1-4503-XXXX-X/18/06…$15.00
https://doi.org/10.1145/1122445.1122456

The data was collected between January 16th and 31st 2023, we only considered the first 100 top results given by Google Scholar but future work should include more papers. To decide whether a paper truly focuses on human interaction, papers were screened based on their titles, abstracts, keywords, contents and publication venues. Out of the 100 papers selected initially, 18 of them were previously published review papers that did not directly address the use of digital twins for human-robot interaction, 20 papers were excluded and not focused on HRI. 62 papers were finally included and used as data for the present analysis.

## 3 STATISTICS

Below we present some statistics about the data.

### 3.1 Publication dates and types

The use of digital twins for HRI is in its early phases, as shown in Fig. 1. The vast majority of the papers were published within the last three years with 30 in 2022, 12 in 2021 and 5 in 2020. Publications were approximately equivalent in types, journals articles were slightly preferred over conference papers, cf. Fig. 2.

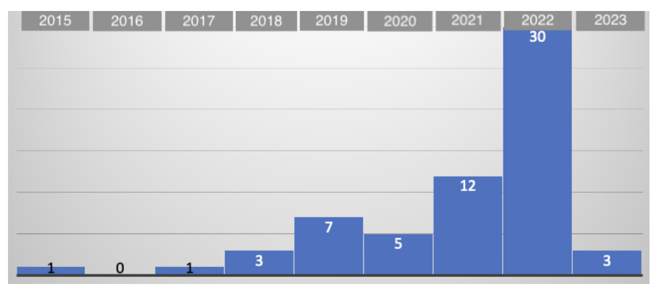


**Figure 1: Histogram of publication dates**

### 3.2 Geographical locations of authors

The countries of authors have been extracted from each publication and classified into two categories: the main author's country (described as the primary location) and the co-authors' countries (described as the secondary location).

The 62 publications originate from 20 different countries, including 17 international collaborations bringing together up to three different countries, but the large majority of the collaborations were limited to two neighbouring countries. Fig. 3 shows the primary countries of the publications and Fig. 4 shows the secondary countries of the publications.

As shown in these figures, China is the most active country with 17 primary publications out 62, followed by the the UK (7 primary, 3 secondary), Italy (7 primary, 1 secondary), the USA (5

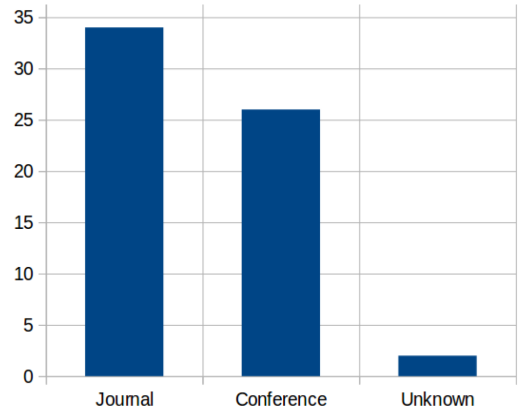


**Figure 2: Histogram of publication types**

primary, 3 secondary), Denmark (6 primary), Germany (3 primary, 2 secondary), Sweden (2 primary, 3 secondary), Estonia (3 primary), South Korea (2 primary, 1 secondary), Japan (2 primary), Greece (2 primary), France (1 primary, 1 secondary), Hungary (1 primary, 1 secondary), New Zealand (1 primary), Australia (1 secondary), India (1 primary), Switzerland (1 primary), Canada (1 primary), Ireland (1 secondary), Austria (1 secondary).

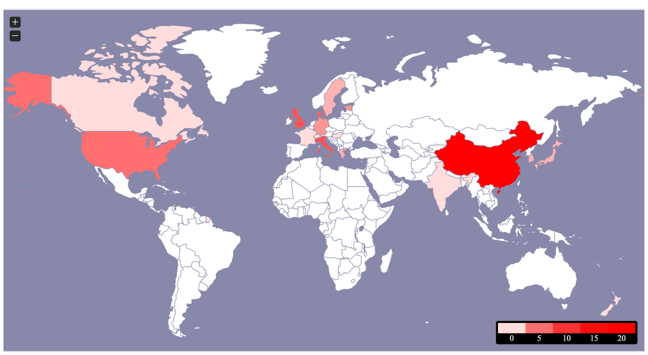


**Figure 3: Primary countries of the main authors**

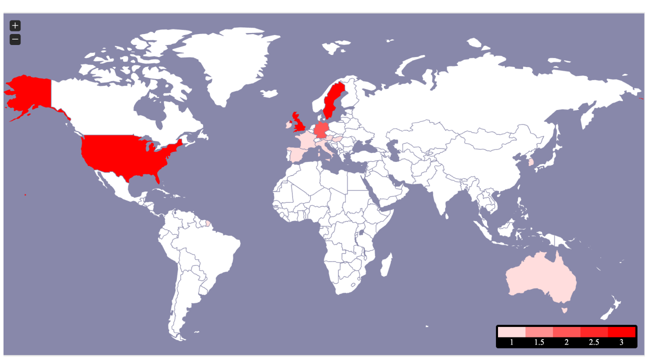


**Figure 4: Secondary countries of co-authors**

### 3.3 Main areas of applications

To get an idea of the main areas of applications of digital twins for HRI, we performed a manual screening of the papers and classified them into different sectors, as shown in Fig.5. A large number of the studies (42%) were performed for the manufacturing/assembly sector. Other applications included general human-robot collaboration tasks (16%), safety and risk assessment (11%), construction (6%), socially assistive robotics (5%), design and ergonomics (5%), smart homes/buildings (3%), nuclear and dangerous environments (3%), unmanned aerial vehicles (UAVs) (1%), offshore energy (2%), space/satellite (2%), warehouse (2%) and telemedecine (2%).

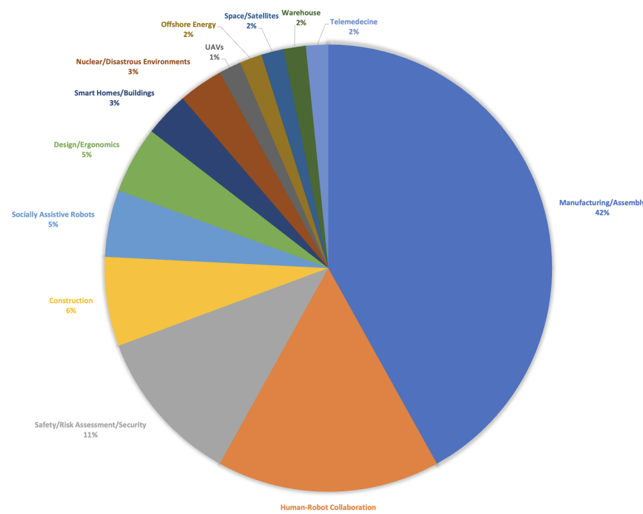


**Figure 5: Areas of application for digital twins in HRI**

## 4 TOPIC MODELLING

Main themes and topics were extracted from the titles, keywords and abstracts of the papers using Orange topic modelling tool [4]. We cleaned the corpora by filtering out stopwords (i.e. most common English words) that have little or no meaning.

The resulting word clouds from the titles, keywords and abstracts are shown in Figs. 6, 7 and 8, respectively. As we can see, the main themes of digital twins, human-robot collaboration, interaction are highlighted in the word clouds of the titles (Fig. 6) and of the keywords (Fig. 7), however the word cloud of the abstracts (cf. Fig. 8) puts less emphasis on the interaction and collaboration aspects but focuses more on the potential applications such as assembly.

Fig. 9 shows the top bigrams (i.e. group of two words) that were found in the abstract corpus. As expected, the top bigrams include the main topic of this paper, with words such as “digital twins”, “human robot”, “robot collaboration” and “robot interaction”. But the bigrams also inform us about the techniques, tools or applications used during the research experiments such as “mixed reality”, “cyber physical”, “virtual reality” and “assembly process”.

## 5 CLUSTERING

With clustering we attempt to group similar papers together based on texts from their titles and abstracts. We used the hierarchical


**Figure 6: Word cloud based on papers' titles**


**Figure 7: Word cloud based on papers' keywords**


**Figure 8: Word cloud based on papers' abstracts**

clustering tool [6] in Orange and fixed the number of cluster to ten, arbitrarily. The resulting clusters are shown in Fig. 10.

We can see that for some clusters such as C1, C3, C6 and C8, papers were grouped almost as exactly as from the manual annotations. But for some other clusters such as C2 and C10, we find some big differences between their respective areas of application

| | Method | Score |
|---|---|---|
| 1 | digital twin | 377.831 |
| 2 | human robot | 216.354 |
| 3 | real time | 173.665 |
| 4 | robot collaboration | 104.999 |
| 5 | digital twins | 81.922 |
| 6 | mixed reality | 56.185 |
| 7 | cyber physical | 54.656 |
| 8 | robot collaborative | 54.259 |
| 9 | robot interaction | 45.543 |
| 10 | collaborative assembly | 44.756 |
| 11 | virtual reality | 43.260 |
| 12 | collaboration hrc | 28.824 |
| 13 | twin dt | 17.885 |
| 14 | assembly process | 17.493 |

**Figure 9: Top bigrams based on papers' abstracts**

e.g. UAVs, construction, telemedecine and manufacturing. It should be noted that during the manual annotations, it was difficult to assign an area of application to some papers, as this information was not always clearly available from looking at the title, keyword or abstract but required reading the content of the paper.

The ten clusters are then projected into the 2D plan using multi-dimensional scaling (MDS) [2]. The result is shown in Fig. 11, with clusters ranked in the temporal order along the x-axis, i.e. the far left cluster corresponds to a publication in 2015 and the far right clusters correspond to papers published in 2023.

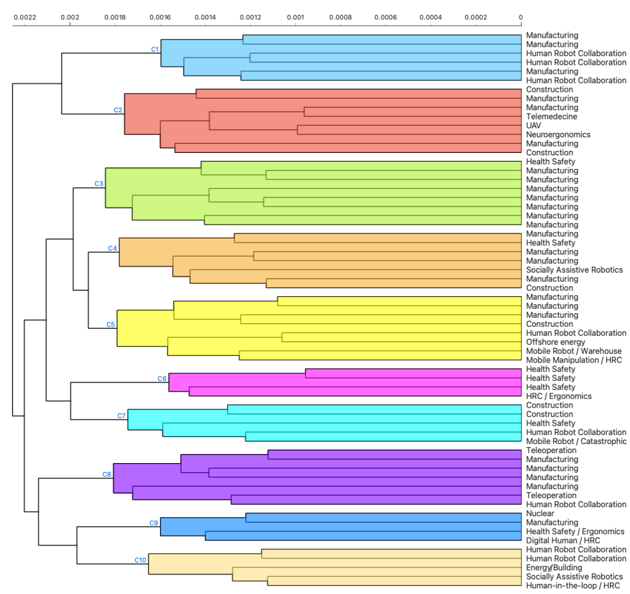


**Figure 10: Hierarchical clustering results alongside the manual annotations of the main areas of applications.**

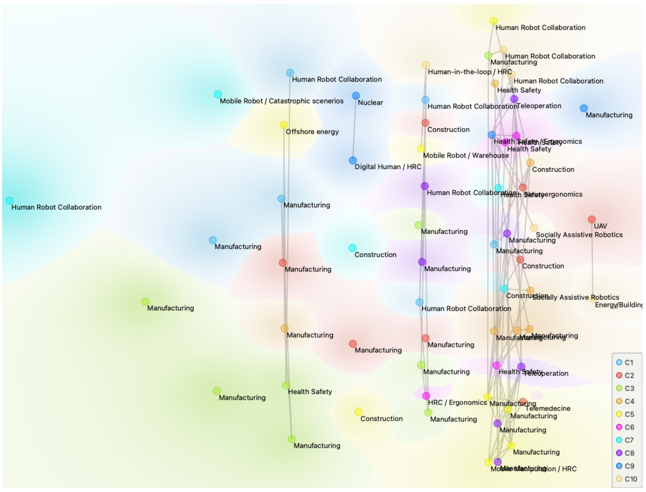


**Figure 11: 2D projection of clusters by multi-dimensional scaling (MDS) in a temporal order (far left cluster: 2015, far right cluster: 2023)**

## 6 SENTIMENT ANALYSIS

We performed sentiment analysis on the corpus of abstracts to examine whether the emotion in the papers is positive, negative or neutral. One could imagine that scientific articles only report facts that may be regarded as neutral. But one could also imagine that with the excitement around novel technologies such as autonomous vehicles, digital twins or artificial intelligence, society creates a hype that can encourage researchers to promote their work as the solution to some challenges faced by these technologies.

We used Orange's sentiment analysis module with Vader method from NLTK. This module predicts the sentiment from text by first scoring each sentence and then averaging these scores into a final score. Fig. 12 shows the workflow for the sentiment analysis and the result is shown in Fig. 13 as a Blue-Green-Yellow heatmap with blue, green and yellow corresponding to negative, neutral and positive sentiments, respectively.

On one hand, two abstracts have the lowest (blue) scores and are classified as having a negative sentiment. A closer look at the vocabulary used in the most negative text (score=-0.8885) confirms this result. For example, we find words such as "potential attack", "damage to the surrounding humans and facilities", " person in the middle attack" and "collapse of the cyber physical system" [1]. The second most negative (score=-0.5859) text contains words such as "putting humans at risk" or "emergency response" [7].

On the other hand, two abstracts have the highest scores and are classified as very positive. One abstract contains words such as "interesting opportunities", "perceived value", "potential usefulness" [3]. The other abstract talks about "key technology", "a new chance", "a more flexible interactive mode" and "improve machine efficiency and operation safely" [5].

## 7 DISCUSSION

This work in progress aimed to explore research works about digital twins for human-robot interaction using text mining techniques.

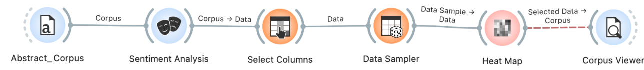


**Figure 12: Workflow for sentiment analysis**

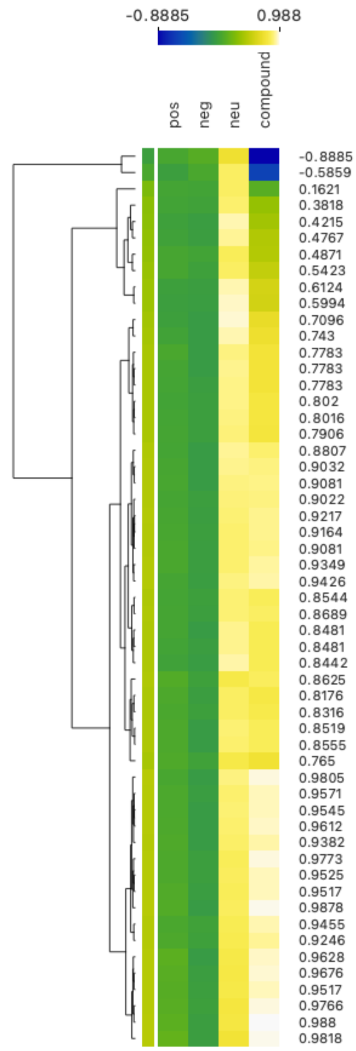


**Figure 13: Heatmap of the sentiment analysis results by order of sentiment (blue: negative, green: neutral, yellow: positive).**

The results of topic modelling, clustering and sentiment analysis provide some useful insights about the data and motivate for further and deeper analysis of the papers' contents. But the data used for text mining is relatively small to make any general conclusions, future work will require a larger number of publications to help identify research trends and gaps in the use of digital twins for HRI.

## REFERENCES


[1] Christopher Carr, Shenglin Wang, Peng Wang, and Liangxiu Han. 2022. Attacking Digital Twins of Robotic Systems to Compromise Security and Safety. *arXiv preprint arXiv:2211.09507* (2022).

[2] J Douglas Carroll and Phipps Arabie. 1998. Multidimensional scaling. *Measurement, judgment and decision making* (1998), 179–250.

[3] Lucia Cascone, Michele Nappi, Fabio Narducci, and Ignazio Passero. 2021. DTPAAL: Digital twinning pepper and ambient assisted living. *IEEE Transactions on Industrial Informatics* 18, 2 (2021), 1397–1404.

[4] Janez Demšar, Tomaž Curk, Aleš Erjavec, Črt Gorup, Tomaž Hočevar, Mitar Milutinovič, Martin Možina, Matija Polajnar, Marko Toplak, Anže Starič, et al. 2013. Orange: data mining toolbox in Python. *the Journal of machine Learning research* 14, 1 (2013), 2349–2353.

[5] Xin Ma, Fei Tao, Meng Zhang, Tian Wang, and Ying Zuo. 2019. Digital twin enhanced human-machine interaction in product lifecycle. *Procedia Cirp* 83 (2019), 789–793.

[6] Frank Nielsen and Frank Nielsen. 2016. Hierarchical clustering. *Introduction to HPC with MPI for Data Science* (2016), 195–211.

[7] Èric Pairet, Paola Ardón, Xingkun Liu, José Lopes, Helen Hastie, and Katrin S Lohan. 2019. A digital twin for human-robot interaction. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 372–372.

[8] Concetta Semeraro, Mario Lezoche, Hervé Panetto, and Michele Dassisti. 2021. Digital twin paradigm: A systematic literature review. *Computers in Industry* 130 (2021), 103469.

[9] Michael Walker, Thao Phung, Tathagata Chakraborti, Tom Williams, and Daniel Szafir. 2022. Virtual, augmented, and mixed reality for human-robot interaction: A survey and virtual design element taxonomy. *arXiv preprint arXiv:2202.11249* (2022).