



UNIVERSIDADE ESTADUAL PAULISTA
“JÚLIO DE MESQUITA FILHO”
Câmpus de Ilha Solteira

Faculdade de Engenharia

Neural Networks: Enhancing Smart Systems with Machine Learning



Gabriel D. Silva

Student

Douglas D. Bueno

Advisor

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RESEARCH REPORT

The present report approaches a way to improve smart systems. Through artificial intelligence applied in the mechanical engineering field, it provides a consistent algorithm that can read data, train the machine and provides results about the situation and what to do with it. It will be studied two cases, one of them using machine learning classical techniques to determine the forces applied to a unnamed aerial vehicle and other using deep learning techniques like neural networks in the structural health monitoring area.

Complete after the research is done.

Keywords: machine learning, structural health monitoring, unnamed aerial vehicle

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LIST OF ABBREVIATION

AI Artificial Intelligence

BD Big Data

CNN Convolutional Neural Networks

DL Deep Learning

IoT Internet of Things

MEMS Micro Electromechanical Systems

ML Machine Learning

NN Neural Networks

SHM Structural Health Monitoring

UAV Unmanned Aerial Vehicle

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1 INTRODUCTION

The use of AI is very present nowadays [32, 40, 41]. This area of statistics neither is new nor started just now with the autonomous cars and voice assistants [38], but it is clear that in the last years it has been increasingly gaining more popularity. This happens mainly because of the advances that the World Wide Web has been had over the years [33, 13], since dial-up internet connection, back in the eighties, until now, with broadband internet and smartphones equipped with 5G connection. Another factor is that in the past, the cost to get a large capacity of storage memory was significantly more expensive than it is now, what makes today cheaper and easy to get memory to store information [23]. With the amount of data available, the evolution of internet and storage capacity, now it is not difficult to obtain, keep and analyze databases to make decisions [17].

AI application is everywhere and today, more than ever, it is easy to realize that. Either to get multimedia recommendations on streaming platforms, like occurs at Netflix, YouTube, Spotify, and so many others platforms [12], or to make predictions on the financial market and sports betting [37, 29, 26], AI is there behind the scenes making all the magic happen. Evidently there is nothing really magical about them, it is pure mathematics combined with a programming language that produces the algorithm capable of doing those things [24, 3, 42, 43]. The launch of ChatGPT-3, and shortly thereafter ChatGPT-4, has shown the power of those technologies and how they can change the way people do things [10, 9, 34, 6].

Getting into the smart systems application, the use of AI is widely used to SHM, which is heavily used in the aerospace and civil fields, [5, 54]. The level and the complexity of the AI to be applied to monitor the structure, whether is going to use DL and NN or simpler methods of ML like regressions, is determined by the problem itself and the results desired [19]. In some cases, the standards methods use numerical techniques and they may not be feasible, especially when there is a huge data to be analyzed. Thus, taking the AI road is an alternative to get the needed results for the monitoring in a more practical way [48, 50].

Still in this context, but in the field of UAV, the use of AI can be combined to integrate UAV through wireless communication networks [31] what can be useful in the agriculture

sphere [1] with technologies like IoT [52, 51]. Also, the use of the AI can be subtle, such as the use of a built-in MATLAB function to make a simple NN to determine the final pose of a UAV based on the initial pose and the forces applied on it [21], or can be more sophisticated, like the use of ML and DL algorithms to predict materials properties, design new materials, discover new mechanisms and control real dynamic systems [25, 2].

It is clear, therefore, that AI can transit into different fields, such as entertainment, business, health care, marketing, financial, agriculture, engineering, among others [44, 55, 16, 53, 36, 39, 22]. The use of the BD can not only make it clear the scenario to be studied, but also to support making strategical decisions [27, 30]. The internet and hardware improvement [7], alongside the facility to storage data with accessible costs, encourages the AI use due to the benefits it can provide.

1.1 Objective

To develop an AI algorithm based on NN to apply in smart systems. The studied cases are:

- determination of the forces used to move an UAV based on its initial and final pose; and
- crack detection on railways through computational graphing¹ from images captured by UAV for SHM.

¹Image recognition

2 METHODOLOGY

This chapter deals with the history, the main concepts and some practical cases of SHM inside the industry and academic area, besides showing how it may be used in the railway crack detection context. Next, in the dynamic field, it will be studied the main mechanical concepts to get the necessary understanding to an UAV motion as well the basics to know how an UAV can be controlled. Then, it will be shown the mathematics behind the algorithms of deep learning that will be implemented in the [Chapter 3](#). Finally, the way how the algorithms are going to be implemented and the tools necessary to achieve the desired neural network.

2.1 Structural Health Monitoring

2.1.1 Definition

According to Balageas et al. [8], the SHM main purpose is to provide, during the life of a structure, a diagnosis of: the state of the constituent material; the different parts of the structure; and the full assembly of each part that makes the structure as a whole. It is an improved way to make non-destructive evaluation. It can be applied in several areas such as civil infrastructure, like bridges and buildings; aerospace, like airplanes and spaceships; and mechanical, like machines.

Furthermore, it also can be associated as an analogy to the human nervous system. Just like the sensors send a signal to the central processor, the human senses send a signal to the brain to make the recognition of what is happening.

2.1.2 Brief History

The SHM development began back in the 20th century and it has been coupled with the evolution of the digital computing hardware, what allowed the costs of the applied techniques less expensive over time.

It all starts back in the early 1970s and 1980s. The oil industry tried to develop vibration-based damage identification methods for offshore platforms by simulating damage scenarios, examining the changes in the resonant frequencies and correlating them with those measured on a platform. In the same period, the aerospace community stud-

ied vibration-based damage identification along with the development of the space shuttle. From that, it was developed the shuttle modal inspection system which aimed to identify fatigue damage in components like fuselage panels and control surfaces. The system was so successful that all orbiter vehicles had been periodically subjected to this test. Also, the civil engineering community studied vibration-based damage evaluation of bridge structures and buildings in the late 1980s [18].

From the late 1990s to the early 2000s, Sohn et al. [49] showed the evolution of the techniques used in SHM, analyzing mainly the following factors: the operational evaluation; data acquisition and cleansing; feature extraction; and statistical modeling for feature discrimination. He also verified that the statistical pattern recognition had not been embraced by the researchers to be more often used in such matter.

Nowadays, in order to contour inherent issues of SHM methods, as large computational effort and hand-crafted work that results in poor classification performance, many deep learning techniques have been used, such as CNN [4].

2.1.3 Main Techniques

Accelerometers

The use of accelerometers is consolidated in the engineering community to be used in several areas and it is present in the people daily life in things like game consoles, smartphones, and tablets.

MEMS sensor have several applications in measuring linear acceleration or angular motion along axis as an input to control a system. MEMS accelerometer sensors often measure the movement of a mass with a position-measuring interface circuit that is converted into a digital electrical signal by an analog-to-digital converter for digital processing [15].

In SHM situation, the accelerometers are in the MEMS. The MEMS are, then, embedded in the structure and can provide information about the structure by detecting low-amplitude and low-frequency vibrations that are not always viable with the conventional low-cost sensor boards [45].

There are many others sensors used in vibration-base techniques like velocity and displacement sensors, however the accelerometers are widely used for this purpose.

Piezoelectric materials

When dealing with acoustic-based techniques, the use of piezoelectric materials as sensor is a great choice due to its ability to respond to stimuli, incorporation, and compatibility with construction materials. Beyond that, these materials are relatively cost-efficient and can sense vibrations in the structures they are installed [28].

Piezoelectric materials and their main property were discovered back in 1880 [14]. The phenomenon is that by the application of pressure in those kinds of materials in the correct direction, it is observed the production of a potential difference and consequently an electrical charge. Examples of materials that are piezoelectric are quartz, zinc, sodium chlorate, tourmaline, calamine, topaz, tartaric acid, cane sugar, and others [11].

The application of these materials in SHM is basically to install the piezoelectric sensor in the structure intend to be monitored and through the tension or compression in it done, a sign will be sent to the central system by the potential differential. The signal indicates that something not usual is happening in the structure. Of course there are levels of the signals and each case must be evaluated in its context. In the last years the use of piezoelectric materials has been capable to identify failures, like the presence of delamination damage, as long as the piezoelectric sensors are close to the damage [35].

Optical-based

The use of digital cameras to detect any kind of irregularity in the surface is also a way to monitor the structure, mainly in the surface areas. The camera itself may be static in a strategical position that allow it to provide good images to be analyzed or can be embedded in the structure itself or in an UAV that will surround it.

To automate and improve the accuracy of the damage detection, image processing techniques are employed, that being a non-conventional approach [47]. In the civil engineering context, it is commonly utilized computer vision to damage detection [20] and also UAV integrated in the same local as the structures for SHM [46].

Many of the images obtained can have their not only the images improved by AI, but also the analyses can take advantage of it.

2.1.4 *Railway*

2.1.5 *SHM and Crack Detection on Railway*

2.2 **UAV Dynamics**

2.2.1 *Control Methods*

2.2.2 *Forces Involved*

2.3 **Neural Networks**

2.3.1 *Deep Learning*

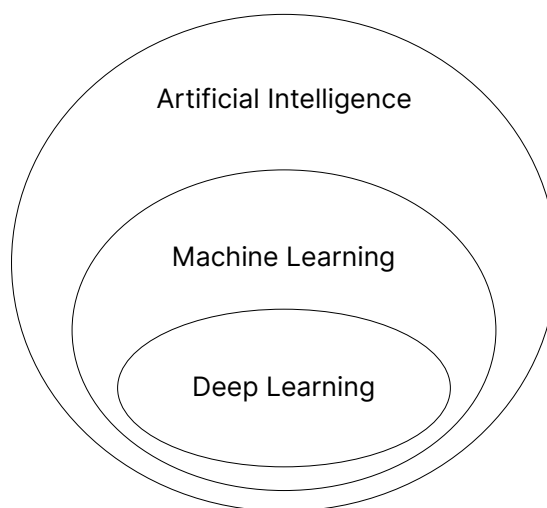


Figure 2.3.1. Subareas of Artificial Intelligence

2.3.2 *Perceptron*

2.3.3 *Convolutional Neural Network*

2.4 **Algorithm Implementation**

2.4.1 *MATLAB Algorithm to Determine the Forces*

2.4.2 *PyTorch Algorithm to Detect Railway Cracks*

3 RESULTS AND DISCUSSION

4 CONCLUSION

BIBLIOGRAPHY

- [1] Ahirwar, S., R. Swarnkar, S. Bhukya, and G. Namwade (2019, January). Application of Drone in Agriculture. *International Journal of Current Microbiology and Applied Sciences* 8(01), 2500–2505.
- [2] Assilian, S. (1974). *Artificial Intelligence in the Controle of Real Dynamic Systems*. Ph. D. thesis, Queen Mary University of London.
- [3] Aurélien, G. (2022). *Hands-on Machine Learning with Scikit-Learn, Keras, and TensorFlow*. O'Reilly Media, Inc.
- [4] Avci, O., O. Abdeljaber, S. Kiranyaz, and D. Inman (2017). Structural Damage Detection in Real Time: Implementation of 1D Convolutional Neural Networks for SHM Applications. In C. Niezrecki (Ed.), *Structural Health Monitoring & Damage Detection, Volume 7*, pp. 49–54. Cham: Springer International Publishing.
- [5] Azimi, M., A. Eslamlou, and G. Pekcan (2020, May). Data-Driven Structural Health Monitoring and Damage Detection through Deep Learning: State-of-the-Art Review. *Sensors* 20(10), 2778.
- [6] Baidoo-Anu, D. and L. Owusu Ansah (2023). Education in the Era of Generative Artificial Intelligence (AI): Understanding the Potential Benefits of ChatGPT in Promoting Teaching and Learning. *SSRN Electronic Journal*.
- [7] Baji, T. (2018, March). Evolution of the GPU Device widely used in AI and Massive Parallel Processing. In *2018 IEEE 2nd Electron Devices Technology and Manufacturing Conference (EDTM)*, Kobe, pp. 7–9. IEEE.
- [8] Balageas, D., C.-P. Fritzen, and A. Güemes (2010). *Structural Health Monitoring*, Volume 90. John Wiley & Sons.
- [9] Biswas, S. S. (2023a, March). Potential Use of Chat GPT in Global Warming. *Annals of Biomedical Engineering*.
- [10] Biswas, S. S. (2023b, March). Role of Chat GPT in Public Health. *Annals of Biomedical Engineering*.

- [11] Brown, C., R. Kell, R. Taylor, and L. Thomas (1962, December). Piezoelectric Materials, A Review of Progress. *IRE Transactions on Component Parts* 9(4), 193–211.
- [12] Chan-Olmsted, S. M. (2019, October). A Review of Artificial Intelligence Adoptions in the Media Industry. *International Journal on Media Management* 21(3-4), 193–215.
- [13] Cohen-Almagor, R. (2011, April). Internet History:. *International Journal of Technoethics* 2(2), 45–64.
- [14] Curie, J. and P. Curie (1880). Développement par compression de l'électricité polaire dans les cristaux hémiedres à faces inclinées. *Bulletin de la Société minéralogique de France* 3(4), 90–93.
- [15] Dadafshar, M. (2014). Accelerometer and Gyroscopes Sensors: Operation, Sensing, and Applications. *Maxim Integrated [online]*.
- [16] Davenport, T. and R. Kalakota (2019, June). The potential for artificial intelligence in healthcare. *Future Healthcare Journal* 6(2), 94–98.
- [17] Duan, Y., J. S. Edwards, and Y. K. Dwivedi (2019, October). Artificial intelligence for decision making in the era of Big Data – evolution, challenges and research agenda. *International Journal of Information Management* 48, 63–71.
- [18] Farrar, C. R. and K. Worden (2007, February). An introduction to structural health monitoring. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 365(1851), 303–315.
- [19] Farrar, C. R. and K. Worden (2012). *Structural Health Monitoring: A Machine Learning Perspective*. John Wiley & Sons.
- [20] Feng, D. and M. Q. Feng (2018, February). Computer vision for SHM of civil infrastructure: From dynamic response measurement to damage detection – A review. *Engineering Structures* 156, 105–117.
- [21] Geronel, R. S., R. M. Botez, and D. D. Bueno (2023, January). Dynamic responses due to the Dryden gust of an autonomous quadrotor UAV carrying a payload. *The Aeronautical Journal* 127(1307), 116–138.

- [22] Ghatrehsamani, S., G. Jha, W. Dutta, F. Molaei, F. Nazrul, M. Fortin, S. Bansal, U. Debangshi, and J. Neupane (2023, January). Artificial Intelligence Tools and Techniques to Combat Herbicide Resistant Weeds—A Review. *Sustainability* 15(3), 1843.
- [23] Goda, K. and M. Kitsuregawa (2012, May). The History of Storage Systems. *Proceedings of the IEEE* 100(Special Centennial Issue), 1433–1440.
- [24] Goodfellow, I., Y. Bengio, and A. Courville (2016). *Deep Learning*. MIT Press.
- [25] Guo, K., Z. Yang, C.-H. Yu, and M. J. Buehler (2021). Artificial intelligence and machine learning in design of mechanical materials. *Materials Horizons* 8(4), 1153–1172.
- [26] Hubáček, O., G. Šourek, and F. Železný (2019, April). Exploiting sports-betting market using machine learning. *International Journal of Forecasting* 35(2), 783–796.
- [27] Jeble, S., S. Kumari, and Y. Patil (2018, January). Role of Big Data in Decision Making. *Operations and Supply Chain Management: An International Journal*, 36–44.
- [28] Jiao, P., K.-J. I. Egbe, Y. Xie, A. Matin Nazar, and A. H. Alavi (2020, July). Piezo-electric Sensing Techniques in Structural Health Monitoring: A State-of-the-Art Review. *Sensors* 20(13), 3730.
- [29] Kollár, A. (2021, March). Betting models using AI: A review on ANN, SVM, and Markov Chain. Preprint, Open Science Framework.
- [30] Kościelniak, H. and A. Puto (2015). BIG DATA in Decision Making Processes of Enterprises. *Procedia Computer Science* 65, 1052–1058.
- [31] Lahmeri, M.-A., M. A. Kishk, and M.-S. Alouini (2021). Artificial Intelligence for UAV-Enabled Wireless Networks: A Survey. *IEEE Open Journal of the Communications Society* 2, 1015–1040.
- [32] Lee, R. S. T. (2020). *Artificial Intelligence in Daily Life*. Singapore: Springer Singapore.
- [33] Leiner, B. M., V. G. Cerf, D. D. Clark, R. E. Kahn, L. Kleinrock, D. C. Lynch, J. Postel, L. G. Roberts, and S. Wolff (2009, October). A brief history of the internet. *ACM SIGCOMM Computer Communication Review* 39(5), 22–31.

- [34] Lund, B. D. and T. Wang (2023, February). Chatting about ChatGPT: How may AI and GPT impact academia and libraries? *Library Hi Tech News*.
- [35] Maio, C. E. B. (2011, March). *Técnicas para monitoramento de integridade estrutural usando sensores e atuadores piezoelétricos*. Mestrado em Dinâmica das Máquinas e Sistemas, Universidade de São Paulo, São Carlos.
- [36] Mhlanga, D. (2020, July). Industry 4.0 in Finance: The Impact of Artificial Intelligence (AI) on Digital Financial Inclusion. *International Journal of Financial Studies* 8(3), 45.
- [37] Milana, C. and A. Ashta (2021, May). Artificial intelligence techniques in finance and financial markets: A survey of the literature. *Strategic Change* 30(3), 189–209.
- [38] Muthukrishnan, N., F. Maleki, K. Ovens, C. Reinhold, B. Forghani, and R. Forghani (2020, November). Brief History of Artificial Intelligence. *Neuroimaging Clinics of North America* 30(4), 393–399.
- [39] Pannu, A. (2015). Artificial Intelligence and its Application in Different Areas. 4(10).
- [40] Poola, I. (2017). How Artificial Intelligence in Impacting Real life Everyday. *International Journal for Advance Research and Development* 2(10), 96–100.
- [41] Rabunal, J. R. and J. Dorado (Eds.) (2006). *Artificial Neural Networks in Real-Life Applications*. Hershey PA: Idea Group Pub.
- [42] Raschka, S. (2015). *Python Machine Learning*. Packt Publishing Ltd.
- [43] Raschka, S., Y. H. Liu, V. Mirjalili, and D. Dzhulgakov (2022). *Machine Learning with PyTorch and Scikit-Learn: Develop Machine Learning and Deep Learning Models with Python*. Packt Publishing Ltd.
- [44] Ruiz-Real, J. L., J. Uribe-Toril, J. A. Torres, and J. De Pablo (2020, October). Artificial Intelligence in Business and Economics Research: Trends and Future. *Journal of Business Economics and Management* 22(1), 98–117.
- [45] Sabato, A., C. Niezrecki, and G. Fortino (2017, January). Wireless MEMS-Based Accelerometer Sensor Boards for Structural Vibration Monitoring: A Review. *IEEE Sensors Journal* 17(2), 226–235.

- [46] Sankarasrinivasan, S., E. Balasubramanian, K. Karthik, U. Chandrasekar, and R. Gupta (2015). Health Monitoring of Civil Structures with Integrated UAV and Image Processing System. *Procedia Computer Science* 54, 508–515.
- [47] Sharma, A. and N. Mehta (2016, August). Structural Health Monitoring Using Image Processing Techniques-A Review.
- [48] Smarsly, K., K. Lehner, and D. Hartmann (2007). Structural Health Monitoring based on Artificial Intelligence Techniques. In *Computing in Civil Engineering (2007)*, pp. 111–118.
- [49] Sohn, H., C. R. Farrar, F. Hemez, and J. Czarnecki (2003). A Review of Structural Health Monitoring Literature 1996 – 200. *Los Alamos National Laboratory, USA* 1, 16.
- [50] Sun, L., Z. Shang, Y. Xia, S. Bhowmick, and S. Nagarajaiah (2020). Review of Bridge Structural Health Monitoring Aided by Big Data and Artificial Intelligence: From Condition Assessment to Damage Detection. *Journal of Structural Engineering* 146.
- [51] Tzounis, A., N. Katsoulas, T. Bartzanas, and C. Kittas (2017, December). Internet of Things in agriculture, recent advances and future challenges. *Biosystems Engineering* 164, 31–48.
- [52] Verdouw, C., S. Wolfert, and B. Tekinerdogan (2016, January). Internet of Things in agriculture. *CABI Reviews* 2016, 1–12.
- [53] Verma, S., R. Sharma, S. Deb, and D. Maitra (2021, April). Artificial intelligence in marketing: Systematic review and future research direction. *International Journal of Information Management Data Insights* 1(1), 100002.
- [54] Ye, X., T. Jin, and C. Yun (2019, November). A review on deep learning-based structural health monitoring of civil infrastructures. *Smart Structures and Systems* 24(5), 567–585.
- [55] Yu, K.-H., A. L. Beam, and I. S. Kohane (2018, October). Artificial intelligence in healthcare. *Nature Biomedical Engineering* 2(10), 719–731.