A Systematic Literature Review on Convolutional Neural Networks applied to Single Board Computers

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Abstract. *This work consists of systematically reviewing studies involving applications of convolutional neural network (CNN) algorithms implemented in single board computers (SBC) to verify their feasibility in computer vision (CV) applications. Indicating the main parameters for evaluating the performance of SBCs as the processing time (88.24%) and accuracy (29.41%). Furthermore, the most used SBCs and the motivation for choosing such devices are indicated. The study contributes to help in future works involving CNNs in embedded systems, as well as in discussions about architectures involving deep learning applications.*

1. Introduction

Convolutional Neural Networks (CNN) are the state-of-the-art in computational vision. They are a huge set of robust algorithms which present complex implementations and high computational hardware is necessary to implement them. Conventional computers are usually used for implementing CNNs, since their limitations are overcome with the increase of computational resources. The same is not usually true in applications that require lower-cost embedded systems [Deniz et al. 2017].

In this context, using Single Board Computers (SBC) is usually the adopted solution, since SBCs allow the implementation of CNNs and are commonly used in embedded systems, enabling a set of low-cost and high-performance solutions [Leroux et al. 2017, Ali et al. 2020]. Understanding how complex applications are implemented on these hardwares can be critical for efficient project execution. Moreover, knowing the SBCs commonly used for such applications can lead to an optimal choice of hardwares, allowing the proposition of new ways to solve problems involving computer vision tools.

In this paper, a Systematic Literature Review (SLR) of the state-of-the-art of CNNs applied to SBCs is presented. The article is organized as follows: Section 2 present the methodology used in conducting the SLR; Section 3 present the results obtained and discussions about the results. Finally, Section 4 concludes the work.

2. Methodology

This work aims to analyze and critically evaluate studies aligned to the SLR theme, following the model defined in Kitchenham and Charters (2007) that consists of defining a protocol for the specification of the research with steps described below.

Initially, research questions are defined (Step 1) to outline the progress of the

SLR. Considering the objective of this work, two research questions (RQ) are defined: **RQ1.** "How is it possible to evaluate the performance of SBCs that implement CNNs when performing image classification?" and **RQ2.** "Is it feasible to implement CNN algorithms in SBCs?"

From these research questions it is possible to define a search string composed of keywords that consider the fundamental terms of the topic of the SLR (Step 2). The search string "***"convolutional neural network" AND "classification" AND "single board"***" is used in this SLR to search for studies aligned to the theme in scientific databases (Step 3).

Through inclusion and exclusion criteria (Step 4) and quality criteria defined during the search (Steps 5), the studies that answer the research questions are filtered from the studies found by the search string. Such studies are called primary studies and will compose the SLR [Kitchenham and Charters 2007].

Finally, it is possible to perform data extraction and synthesis (Step 6), which aims to accurately record the information obtained in the primary studies in forms in a quantitative way through a complete and detailed reading of the selected studies [Kitchenham and Charters 2007]. After performing all the steps, it is possible to critically evaluate the primary studies.

3. Results and discutions

The search in the scientific databases result in a total of 70 academic studies in article format. After applying steps 4 and 5, 17 primary studies are selected to compose the SLR and answer the research questions.

All studies address the use of images as the focus of the applications. Of the total, 11 primary studies address image classification. Image recognition appear in 8 studies. Object identification in images is performed in 7 of the primary studies (PS). The studies evaluate the performance of SBCs in different contexts and use them for reasons such as low-cost, low power consumption and to evaluate how they perform when implementing complex algorithms such as CNNs.

Applications that focus on low-cost (45% of PS) choose SBCs to be part of their systems because with such hardwares it is possible to realize applications such as access control and authentication and monitoring systems [Curtin and Matthews 2019, Oliveira and Wehrmeister 2018, Lindner et al. 2020, Nikodem et al. 2020] while maintaining a feasible cost and easy replication. It is also interesting to note that in applications involving systems that promote user accessibility [Calabrese et al. 2020] or that are part of systems that already have a certain high level of cost [Milioto et al. 2017, Nikodem et al. 2020, Kim et al. 2019, Boschi et al. 2020] the low cost of the system is a concern for the authors.

The performance of the SBCs is also considered an important factor in the choice of these hardwares. And depending on the purpose of the application, using a SBC that has less computational resources than the application needs can lead to unnecessary costs and the impossibility of executing the application in the expected way. Thus, some studies experiment with many SBCs so that it's possible to choose the ideal one for the application they propose [Lindner et al. 2020, Sordillo et al. 2021, Leroux et al. 2017, Hossain and jin Lee 2019, Dayal et al. 2021]. The performance of SBCs is mandatory for their choice in 40% of primary studies. Low power consumption and its size is a motivation for their choice in 10% and 5% of primary studies, respectively.

With the synthesis of the studies, it's possible to perceive that the majority (88.24%) evaluates the SBCs according to the processing time of their hardware, since the applications require real-time results. The evaluations of accuracy (29.41% of the PS) and power consumption (17.65% of the PS) appear in studies that perform applications involving pattern recognition, image identification and classification. Recall and used memory are evaluations that scarcely appear in the studies covering, respectively, 11.76% and 5.88% of the primary studies.

It is also possible to identify the SBCs most used in the applications and the evaluations methods of these hardwares. The processing time is evaluated in all 17 primary studies. The Raspberry Pi 3B and NVIDIA Jetson Nano appear in 5 studies that also evaluate power consumption and accuracy. The Raspberry Pi 3B+ appears in 3 studies and its processing time, accuracy, recall, and power consumption are evaluated. Other SBCs from the NVIDIA and Raspberry families appear in some primary studies, but only those that appear in 3 or more studies are considered the most relevant to this SLR.

4. Conclusions

This paper sought to map studies in the literature that could answer the research questions proposed during the development of the SLR. The SLR's primary studies shows how the performance of SBCs that implement CNNs are evaluated, and the main methods used to do this. Besides informing ways to implement them in a feasible way. In some primary studies, the suggestion of new algorithms of CNNs that have the proposal of improving the performance of the SBCs according to the limitations that the devices have and even obtaining better results than using conventional CNNs. It is also identified that the partitioning of CNNs or using versions with fewer layers and/or fewer parameters is the most appropriate way to implement CNNs in SBCs. Since these algorithms optimize the processing time of these applications and do not lose the accuracy of the models.

With this SLR, is intended to provide a reference that can serve as a starting point for new works in the area that focused on image classification applications using SBCs and CNNs. Indicating the best solutions for applications with specific needs. It also contributes to discussions involving the architectures of CNNs.

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