STUDY ON DESIGNING A HIGH-PERFORMANCE IOT SENSOR NODE USING A SINGLE BOARD COMPUTER CLUSTER(SBC)

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***Abstract*— In this paper, we study designing and implementing a high-performance IoT sensor node using a popular Raspberry Pi Single Board Computer (SBC). Modern IoT applications use multiple sensors to sense different physical parameters, including camera sensors. Connecting multiple sensors in a single node drastically reduces the computing power and uptime of the node. Also, it may not get expected performances when it works in real-time. During the design, multiple Raspberry Pi boards are interconnected as a cluster to improve the system's computing power. And a parallel processing algorithm called Massage Transfer Interface (MPI) to share the load within the node. The performances of the cluster have been tested, and results are presented.**

Keywords- Raspberry Pi Clustering, Internet of Things, Sensor node design, Massage Transfer Interface (MPI)

I. INTRODUCTION

Raspberry Pi is a low-cost computer primarily used for embedded systems, IoT applications, data mining, etc. Also, these single board computers can be used in VoIP technology to get a more cheap and convenient way ofcommunicating.[1] We can build a Raspberry Pi cluster by connecting a few Raspberry Pi boards. Most of the time, embedded clusters are used for their high availability, computational power, and low cost, compared to a computerthat runs a single processor to give the same performance. Also, these clusters can be used as a solution for the ever- increasing request traffic of the web servers.[2] With the use of an OctaPi, which means 8 Raspberry Pi boards clustered together, researchers have even tried to break the asymmetric encryption, which is exceptionally computationally intensive[3]. Also, these clusters are being used in highly intensive graphical simulations where we can understand a system's new design without actually having to build it. This is important for real-world applications because we can know whether the system will work or not without actually implementing it. That can save a lot of time and money required for the building process. For example, there is research about designing an aircraft wing, simulating it across the cluster, and working out whether an aircraft that uses the new wing could fly on a full tank of fuel[4]. This can give us an idea about the processing power these embedded clusters have.

There is a cluster head in the cluster, and other modules are cluster members. But to work those to accomplish a task simultaneously, we need to develop an algorithm according to the task. With this cluster system, the performance of the process, time consumption, and energy consumption can be reduced considerably rather than using one Raspberry Pi module. With this research, I concentrate my attention on how a Raspberry Pi cluster can use to improve performance in an IoT sensor node. So, we aim to design and develop an embedded cluster using Raspberry Pi modules that can be used to communicate with the IoT sensor node. There is a cluster head in the cluster, and other modules are cluster members. But to work those to accomplish a task simultaneously, we need to develop an algorithm according to the task. With this cluster system, the performance of the process, time consumption, and energy consumption can be reduced considerably rather than using one Raspberry Pi module. This research concentrated my attention on how a

Raspberry Pi cluster can use to improve performance in an IoT sensor node. In this project, we aim to design and develop an embedded cluster using Raspberry Pi modules that can be used to communicate with the IoT sensor node.

The IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction [5]. IoT technology has rapid growth at present, and it will be at its peak within a concise period with the current rate of development. There are many devices currently controlled with IoT technology, including heart monitor implants, biochips that are used to locate the animals on farms, and the animals that have been endangered. These are only a few examples. There are many uses of IoT. Basically, in an IoT system, sensor nodes gather the data. Then the system can send or act upon the data. According to the user'srequirement, the data analyzing part can be done within the system or in the cloud.

II. RELATED WORKS

Many related works have been conducted on implementing different applications on Raspberry Pi. The project has discussed using a Raspberry Pi cluster for VoIP communication[6]. They have used a cluster of three Raspberry Pi modules with a parallel processing algorithm called Massage Transfer Interface (MPI) to share the load within the node. One board functions as the primary node in this cluster setup, and the other two nodes function as nodes. Then they generated voice calls with each setup at the same time. This system has used free available phone software such as Asterisk and FreePBX. CPU utilization and call count performance data were gathered and analyzed for bothsetups. With that cluster, they have increased their performance at a significant level.

A study of an unconventional low-cost, energy-efficient HPC cluster composed of Raspberry Pi nodes[7]. Their target is to use this cluster in Data mining algorithms which requires a considerable amount of computing power to get reliable results. The main reason to look into these kinds of setups is that High-Performance Computing (HPC) platforms are commonly expensive and power-hungry. In this paper, they have studied a cluster of eight Raspberry Pi modules. They compared the cluster with the coprocessor Intel Xeon Phi for two data mining algorithms: Apriori and K-Means. And they have proved the cluster's performance is better thanthat of the coprocessor. A study of an unconventional low- cost, energy-efficient HPC cluster composed of Raspberry Pi nodes[7]. Their target is to use this cluster in Data mining algorithms which requires a considerable amount of computing power to get reliable results. The main reason to look into these kinds of setups is that High-Performance Computing (HPC) platforms are commonly expensive and power-hungry. In this paper, they have studied a cluster of eight Raspberry Pi modules. They compared the cluster with the coprocessor intel Xeon Phi for two data mining algorithms: Apriori and K-Means. And they have proved thecluster's performance is better than that of the coprocessor.

A set of Raspberry Pi modules for the cluster were interconnected via an Ethernet router and the MPI interface [8]. The primary goal of this development has been to explore the possibility of forming such clusters and their programming based on the MPI concept. A set of images has been processed and measured for its performance. They have used two algorithms: Watershed and Edge detection, with sets of images for each. The single Raspberry module's processing time has been proportional to the number of images for both algorithms. But the cluster's processing time has been approximately the same for both algorithms for a different number of images. A set of Raspberry Pi modules for the cluster were interconnected via an Ethernet router and the MPI interface [8]. The primary goal of this development has been to explore the possibility of forming such clusters and their programming based on the MPI concept. A set of images has been processed and measured for its performance. They have used two algorithms: Watershed and Edge detection, with sets of images for each. The single Raspberry module's processing time has been proportional tothe number of images for both algorithms. But the cluster's processing time has been approximately the same for both algorithms for a different number of images.

Raspberry Pi clustering on data analytics [9]. The target is to create a miniature model of a cluster computer used on servers such as windows. With that model, they aimed to provide the facility of data analysis to demonstrate the power of cluster computing and the uses of data analytics. Also, they assume that these cluster computers will be a cheaper solution for HPC-required areas. They have done this project in a comparison approach, testing for one Raspberry board and then for the cluster. For this project, they have used MapReduce software. Researchers mainly focused on this model for students who need high computational power for their work and cannot afford high-priced systems. Their design idea is a small, compact four-node Hadoop cluster. Raspberry Pi clustering on data analytics [9]. They target creating a miniature model of cluster computers used on servers such as windows. With that model, they aimed to provide the facility of data analysis to demonstrate the power of cluster computing and the uses of data analytics. Also, they assume that these cluster computers will be a cheaper solution for HPC-required areas. They have done this project in a comparison approach, testing for one Raspberry board and then for the cluster. For this project, they have used MapReduce software. Researchers mainly focused on this model for students who need high computational power for their work and cannot afford high-priced systems. Their design idea is a small, compact four-node Hadoop cluster.

Related works were carried out on power management using cluster computers [10]. They have suggested that one way to reduce power usage in large clusters is to use low-power embedded processors. First, their goal was to find a low-cost, low-power, high-performance board suitable for cluster use, so they chose the Raspberry Pi Model 2B. the Raspberry Pi provides several features, including small size, low cost, and minimum cost power consumption, and a well-supported OS. They have combined 25 Raspberry Pi modules with building the cluster. In this paper, the researchers have investigated various power-related matrices for seventeen different ARM development boards. Their idea is to build a custom cluster out of Raspberry Pi boards. It is specially designed for power management.

In this paper, the researchers have focused on using clustering in Securing an Embedded system. They used it on an IDS (Intrusion Detection System) [11]. The security that can provide an IDS is limited against a sophisticated attack. This is why the researchers have focused their attention on a new architecture to improve that weakness. They use it to solve the challenges that IDS faces, such as computational resources and ubiquitous threats. Running IDS on a cluster allows tasks to be parallelly executed. They propose to secure embedded systems by using a cluster of embedded cards (Raspberry Pi, Beagle Board, Cubie Board, Galileo) that can run multiple instances of an IDS in a parallel way. They have run two instances of the Bro IDS on two Raspberry Pi. According to the results, it is positive to effectively run multiple instances of an IDS in a parallel wayon a cluster.

The main goal of this project has been to build a 4-node distributed computing cluster system using the Raspberry Pi single-board computers [12]. This research is done for educational and research purposes mainly. This research discusses the improvement of the efficiency of seismic processing. Their proposed solution for that is to develop parallel and distributed systems. For this, the researchers have chosen MPICH, a high-performance and widely portable implementation of the MPI standard. The main reason to choose MPICH is that it supports both synchronous and asynchronous message passing. They have used a Monte Carlo simulation to calculate π (Pi) to demonstrate the advantages and drawbacks of parallelization and distribution of tasks and data within the cluster.

In the paper [13], the researchers have focused their concern on designing and developing a low-cost Raspberry Pi cluster for use with Wolfram Mathematica. In this research, they aim that the students with financial pressures will be able to work with computationally intensive software like Wolfram without spending a lot of money on a high-performance PC. Moreover, according to the researchers, Wolfram can be used in a Raspberry Pi board without buying the software because of the partnership that the Raspberry Pi and Mathematica have. But the issue is that the Wolfram requires much higher computational power than a single Raspberry Pi. Because of that, they have implemented a Raspberry Pi cluster to work with this software. Also, they have done performance benchmark tests between algorithms executed on one node and four nodes. According to them, this research has provided an opportunity for undergraduate students to work and understand cluster computing.

These researchers have taken the Raspberry Pi clustering to the next level, and they have presented a concept of a Raspberry Pi cluster that consists of 300 nodes [14]. They have aimed to build a system that can run even a very high level of computational and graphical information applications and processes. Also, they have the idea of using this cluster for cloud computing research and as a robust and mobile data center for operating in adverse environments. But according to them, connecting this many numbers of Raspberry Pi nodes can create the drawback of offset. In this paper, they have discussed the initial steps of the system, such as building the cluster, setting up and configuring the hardware and the system software, and monitoring and maintaining the system. Also, they have faced several challenges while implementing the cluster, such as supply power, room for 300 nodes to operate at once, and installing and configuring system software for each node.

This researcher has also focused on building a single board computer cluster for the students, especially for accomplishing their academic goals without spending a lot of money on a high-performance PC [15]. A single-board computer cannot compete with a high-level system like a PC or a workstation. To avoid this issue, the researcher has used the clustering of several nodes. Also, the researcher has analyzed the performance and the energy efficiency of the system by executing the High-Performance LINPACK benchmark using a distinct number of nodes and different proportions of the system's total main memory utilized.

This research uses a Raspberry Pi cluster for parallel programming [16]. In parallel programming, the required computations are executed in multiple processors simultaneously. The ultimate goal of this project has been to provide a product that is economical, scalable, powerful, mobile architecture, and especially that consumes low energy. In this project, the researchers have used a Raspberry Pi cluster with four nodes. This cluster works by a python code distributed from the platform called Jupyter notebook. They have monitored the execution of codes on the Jupyter platform through a browser using the Multi-Tabbed PuTTY (MT PuTTY) program that allows permission for SSH connection to the nodes. And overall, their conclusion has been Raspberry Pi clusters are efficient when emulatinghigh-performance computers.

This paper has addressed some most commonly used frameworks and developments that exploit Raspberry Pi's capabilities, which can be acquired when used in the Pi clusters [17]. Also, they have focused on improving the quality of the clusters with the use of some tools and measures. In this research, the researchers have used three statistical evaluation stages: Data Pre-processing, Constructing a performance Space, and evaluation. According to them, to improve the cluster's performance, a few factors are needed to be addressed. Namely vastness of computation, complexity, and specifications that programmers need to embed. And they have claimed that with the rapid growth of the technology in single-board computers, it will be a viable alternative for many people to study and build real-world applications using these clusters.

III. DESIGN AND IMPLEMENTATION

The proposed system consists of three Raspberry Pi boards, A Monitor, a Wi-Fi router, A Computer, and a Raspberry Pi camera. We use Wi-Fi to communicate among the Raspberry Pi boards and the computer using static IP addresses assigned to each Raspberry Pi board. As shown in Fig.1, we use Raspberry Pi 3B+ boards for this research, which have 1GB of RAM.

As depicted in 'Fig.2', our first task was to set up the Raspberry Pi boards in the implementation process. We had to install Raspberry Pi NOOBS to each SD card. Then boot up each module. Also, one Raspberry Pi would act as the master node in the cluster, and the other two would act as the slave nodes. The master node is responsible for dividing the workload among the slave nodes. Then we installedOpenSSH on Raspberry Pi boards to communicate with the Windows computer. To access the Raspberry Pi modules using our Windows computer, we had to install the PUTTY terminal because it gives SSH access in Windows. After installing PUTTY, we could access each Raspberry Pi module using SSH and do the setup and configuration for each module using our windows computer. Then we had to install the required packages and libraries, including Open MPI to the Raspberry Pi boards. These installations could beeasily done using PUTTY because it provided remote SSH access to each Raspberry Pi module. We needed to install open MPI because it would allow the packages and programs all into multithreaded programs that can run across multiple nodes. This was the main function that was required for the cluster. These were the initial steps of this research. After doing these steps, we tested the cluster using some multithreaded programs like calculating the value of Pi.

After finishing the design and implementation of the cluster, we needed to focus on the area of implementing the IoT sensor node. In this research, we targeted to get a sequence of images from a Raspberry Pi camera module and then run them through a heavy computational process and see how the cluster performs vs. how a single node of the Raspberry Pi module performs.

Fig. 1. Raspberry Pi 3B+

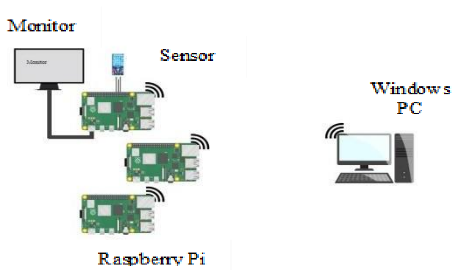

Fig. 2. System Overview

we were able to develop a python code for the above requirement, creating a highly intensive computation with the code. We found out that capturing and processing a high-resolution image from a typical raspberry pi camera module requires approximately six seconds. So, to create the bottleneck that we needed for a single board computer, we decided to reduce the image capture time to two seconds, making the system bottleneck. This code was tested on a single board and it showed that it was bottlenecking the system. So, we proceeded to use the code in the cluster. But the cluster was implemented using the C compiler initially. Hence, we had to install the python compiler to make sure that the implemented code is working in the cluster. But when we tried to install the python compiler, we had to face an issue which was the conflict of the compilers so the python compiler has not been able to install in the cluster. Because of that, we had to follow another path to check the cluster's performance vs a single board. For that, we used the pi calculation algorithm, and we executed it iteratively inside the cluster

IV. TESTING

As shown in Fig.3, the 100 iterations, 500 iterations, 1000 iterations, 2000 iterations, 5000 iterations, and 10000 iterations were used in the code to run iteratively and see the result. The load was increased level by level to get an idea of the system vs. single board. The graph below shows the iteration vs. time of both the cluster and the single board.

`It could be observed that the single board performsbetter when the iterations, which is the low workload. But when it is incremented slowly, the cluster starts to outperform the single node. The original idea of this project was to use an IoT sensor to make the workload to see the performance comparison between the single-node vs. the cluster. But the issue was that the Open MPI library for python was still at the development stage. The released version didn't have the stability at that point to use in this kind of setup. So instead of a python compiler, a C compilerhad to be used. Which the system was capable of executing C programs. And when it comes to integrating the IoT sensor with our developed system, it wasn't possible to do because there wasn't a C library for the IoT platform in which the data was going to be fed.

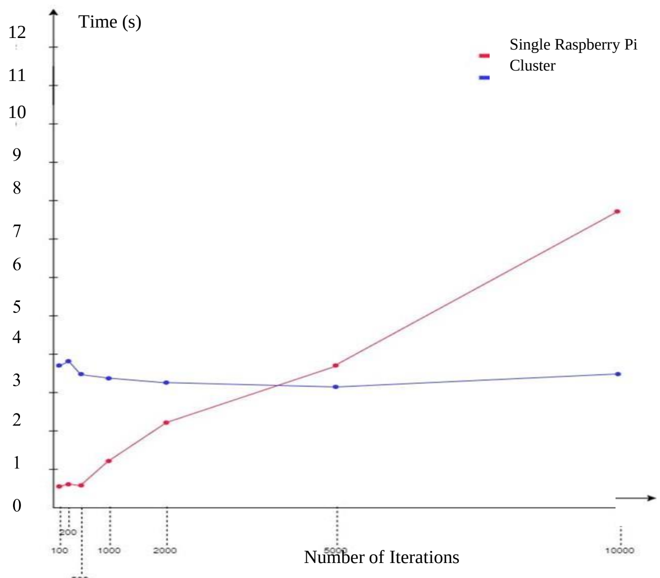

Fig. 3. Working of the cluster and the single board vs time

Due to this, further research had to be done to find a method to do this, but there wasn't a suitable library for the requirement. Thus, the iterative code had to be used to create the workload, and it was successfully managed to do the task.

V. Conclusion

This research aimed to study using the Raspberry Pi cluster as a high-performance sensor node. Three Raspberry Pi boards were used as single-board computers. OpenSSH has been used as a communication method via a Wi-Fi network. Open MPI, an open-source message passing interface, is used to make the multithreaded programs applications. The project hypothesized that a single board computer cluster should be more efficient than a single node. In proving the hypothesis, this project is tied to implementing an IoT sensor node that requires a higherprocessing power than usual to test how the cluster will perform in such a scenario compared to a single node. After finishing the implementation of the system, a comparison was undertaken to determine the performance of the cluster to the performance of a single node that runs the same algorithm. It identified that when the process is simple, the single node is faster because there is less work to do and it doesn't have to communicate between nodes. But when the workload is more, the cluster showed better performance. This was tested with a pi calculation algorithm running 10000 times in both a single node and the cluster.

Hence, through the project results, it is evident that clusters are more efficient than single boards when the workload is high. Thus, proves the hypothesis of this Research Project.

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