Survey of Prototyping Solutions Utilizing Raspberry Pi

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Abstract Sensor networks are a highly researched application area in the field of Internet of Things (IoT). A key cost and resource question in the development of IoT network sensor solutions is prototype implementation. In this study, the Raspberry Pi—a widely used single board computer—is investigated as it is one of the most commonly used prototyping devices available and is also widely used in scientific research. In this paper, we address which technologies, the usefulness and what kinds of issues arise when the prototyping of a sensor network solution is done with Raspberry Pi. The extant literature is studied by selecting papers with the systematic literature review method. Based on an extensive survey of the selected studies, we found several sensor-based implementations where Raspberry Pi has been used. In addition, this survey revealed subjects, such as e-health and education, which expanded the research topic in new ways. Further research opportunities have been identified in specifying the usefulness of various technologies with single board computers.

I. Introduction

The Internet of Things (IoT) is the expansion of Internet services, which connects everyday physical objects to a network. This connection between a network and physical objects makes it possible to access remote sensor data and to control the physical world from a distance. The first mention of the term 'IoT' is said to have come from Kevin Ashton in 1999. A survey of the areas of "Internet of Things" was made by Atzori, Iera and Morabito [1]. In this research, the focus has been redirected toward the Wireless Sensor Network (WSN) type of solution. The basic features of sensor networks were compiled in a survey conducted in 2002 [2].

'Sensor networks' refer to distributed autonomous sensors that are used to monitor the physical environment, e.g., temperature or pressure. Sensor networks are a widely-studied area. For example, the use of embedded Linux for sensor networks has been proposed [3] and a simple model of a sensor network has been introduced earlier [4]. There has also been research on long-range wireless sensor networks with geolocation tracking [5] and on a low energy algorithm for a sensor network [6]. Sensor networks have several development possibilities, such as the one introduced in Fog the gateway unpublished [7] study.

Single-board computers, such as Intel Galileo, BeagleBone and Raspberry Pi, are low-cost development devices for testing or educational purposes. These are fully customizable and programmable, and have the features required to implement small and low-cost IoT devices [8]. The Raspberry Pi is the most popular of these three in the field of research according to the keyword search. Single-board computers are an rising technology area in the development of prototypes. Often, developing a prototype is experienced as difficult and expensive due to the costs of hardware design, software design and developing as well as hardware manufacturing and building. However, by using single-board computers, these costs can be easily reduced. Ready-to-use hardware solutions already exist, such as Raspberry Pi, which have ready-to-use software with embedded Linux. Furthermore, there are many communities and user groups available online where a developer could ask for help and support.

Despite the potential value that single-board computers could provide, we are currently lacking a good overall picture of the studied and tested information on the real benefits and drawbacks brought about by the use of single-board computers. The objective of this study is to fill this research gap by mapping the current state of the art in the use of single-board computers in prototyping sensor networks. Thus, we seek answers to the following research questions:

RQ1: What do we know about the benefits and limitations of using the single-board computer Raspberry Pi in supporting prototyping work?

RQ2: How is the functionality in these single-board systems tested?

RQ3: Are there any specific test methods?

To answer these questions, we performed a literature study. We used the Systematic Literature Review approach (SLR) [9] to collect primary studies regarding this topic. The selected primary studies were then analyzed and categorized with the content analysis method.

The rest of this paper is structured as follows. In Section II, we introduce the research approach used in this literature study. In Section III, we present the analysis of the findings. Section IV includes a discussion and suggestions for future research on the topic and finally, the study is summarized in Section V.

II. Research Approach

As previously mentioned, to answer the presented research questions, we decided to perform a literature study in order to map the extant knowledge on this domain. We decided to use the SLR method for collecting relevant primary studies and followed the guidelines given by Kitchenham and Charters [9].

For the SLR, we decide to do an electronic search. The database used was IEEE Xplore Digital Library, the search engine of which was used in this study. The survey was started by selecting the following search terms: "Raspberry Pi" AND "Internet of Things" AND "Sensor Networks." We decided to use these simple keywords in order to receive good coverage of potential primary studies.

The keywords were commonly used alone: "Raspberry Pi" returned over 500 hits, "Internet of Things" returned over 12,000 hits, and the most popular was the third keyword "Sensor Network," returning over 110,000 hits. Together the keywords returned 11 (IEEE), and 1 (ACM) results. These were only the keyword search. The full text search gave too many hits, over 400, for this research. Nevertheless, this result combined with the search keyword "smart home" gave us 24 hits. The final searches were targeted to keywords and limited only to research papers.

In the first phase of the research, we selected studies based on abstracts. We used the following inclusion and exclusion criteria: Peer-reviewed studies conference and journal articles as well as book sections written in English focusing on all three aspects were included. We excluded studies written in languages other than English, posters, abstracts, and short papers, as well as studies only mentioning the keywords but not focusing on the issue.

In the second phase of the research, the selected studies were read through carefully. In this phase, we still excluded studies unless they focused on the development of sensor networks with Raspberry Pi. In the end, we selected 15 primary studies for inclusion in this study. The selected studies were read through and analyzed. We studied which technologies were used, what kinds of issues were faced, how the testing was reported, and whether there were any problems in testing or not. Finally, the notes were reviewed and the results were analyzed.

In the remaining sections of this paper, we will first present the selected key studies in the section III. This is followed by a discussion section where we answer the presented research questions.

III. Results

In total, we selected 15 relevant primary studies for this paper. The primary studies found and selected were [10-24]. In the following, we will briefly summarize the key primary studies and their findings.

Baranwal, Nikita and Pateiya [10] presents a monitoring system for detecting and preventing rodents in grain stores. The system consists of a webcam, a repeller for undesirable rodents, and Raspberry Pi with a set of sensors, which were an Ultrasonic Range Detector (URD) and a Passive Infrared sensor (PIR). The algorithm for the software was introduced. The test cases consisted of functionality tests where the hardware and software were tested. The test results showed that the observation distance was small, seven centimeters. In addition, the reliability of the system was tested. This test shows that 85 percent of system notifications were real. The 15 percent of tests that were unsuccessful were due to the connectivity of the device, data transmission, notification, and other factors such as PIR sensors being configured to generate discrete values.

Two studies [11] and [12] introduced the developed IoT-based E-learning testbed developed on the basis of a combination of five Raspberry Pis and a microwave sensor. The testbed controlled several factors: Chair Vibrator Control, Light Control, Smell Control, Sound Control, and Remote Control Socket. The purpose was to improve and stimulate the e-learner's motivation by using this testbed. The study introduced the usage of Optimized Link State Route protocol (OLSR) technology in the testbed software. The first study introduced the idea and the second study from the same authors handled the same issue more profoundly. In the second study, the testbed network communication was tested and the results were shown. The testbed usage for improving and stimulating e-learner's motivation was not tested. Also, the functionality of the testbed was not tested apart from the communication protocol.

Mahmoud and Qendri [13] introduced a sensor shield, the Sensorian platform, for Raspberry Pi. The aim was to transform Raspberry Pi into an IoT platform. This study could be categorized as hardware development. The shield consists of sensors: light, accelerometer, temperature, pressure, touchpad. It also includes a TFT display, LEDs, a real clock, and memory for software development. This shield was developed by means of crowdfunding. However, the functionality tests were not presented. It was mentioned regarding software testing that the firmware had been tested with the Raspbian operating system, but no test cases or results were mentioned.

References [14] and [15] focused on education on their research. The first study introduced the challenges and experiences of introducing IoT as an open elective course. The second focused on teaching Python programming. In these courses, Raspberry Pis and a set of sensors were used for teaching purposes. Students on this course built prototypes using the hardware mentioned. These studies did not handle testing the built prototypes and the focus was more on education than the other pieces of research in our study. However, these studies were included because of the good requirement specifications of the systems.

Maksimovic, Vujovic and Perisic introduced IoT-based e-health systems [16]. Their research also highlighted the economic impacts of IoT applications and especially the economic growth of healthcare applications. This research compares different applications: one is the e-health sensor shield V2.0 for Raspberry Pi and the other is a custom-made body sensor measuring system. Both enable data gathering and sending to the server application. This research does not have any special testing part but the research extensively points out the security issues of the gathered data.

The research by Hsiao, Liang and Sung [17] introduced a smart home system. This system uses infrared communication inside a room, Zigbee communication inside the house, and Wifi communication for data transfer to the cloud. The research focus was the combination of communication types in one system. The actual sensor or controller was not introduced. The features of these communication methods were also compared. A comparison of different means of communication was made at a general level, but no specific test cases were presented.

Hentschel, Jacob, Singer and Chalmers [18] introduced a smart campus system based on Raspberry Pis. This system uses hardware-software-service architecture, where the hardware consists of Raspberry Pis and sensors. This combination has software for collecting and sending data. The cloud has a service where the data are stored and served. This research presents sensor-to-sensor technology and delay-tolerant data transfer. This is for not-so-urgent data in the case of disrupted network connectivity. This research described several use cases of the system: Room temperature, free meeting room, room occupancy, custom event triggering, and robotic support infrastructure. These use cases are interesting but the physical test cases for them were not described. There were a few cases where the improvement of hardware design was introduced by changing the type of sensors.

As above, sensor network based systems were introduced in several studies [19-24]. These systems present the different ways to use master node - sensor node type solutions. Common to all these studies was the model of one master node and several sensor nodes. The sensor nodes collect the data and send it to the master node. The master node processes the data or sends it to the cloud service. These studies present systems from different angles or focus only one part of the system. In these studies, the test cases focused on functionality tests, communication test, or processing power tests. These tests usually support the main ideas of the studies and test cases which did not support them were dealt with.

IV. DISCUSSION

This study aims to resolve three research questions: What do we know about the benefits and limitations of using the single-board computer Raspberry Pi in supporting prototyping work (RQ1); how are the functionalities in these single-board systems tested (RQ2); and, finally, are there any specific test cases (RQ3)?

To answer the first research question, it can be said that there are a reasonable number of studies focusing on prototyping sensor networks with Raspberry Pi devices. However, most of the papers reported a single case study on the development of an interesting system. There is a clear lack of formalized approaches, methods, and tools.

The second research question dealt with the practices used in the testing of a prototyped Raspberry Pi sensor network solution. Again, only little has been reported on the testing practices utilized, problems faced, and approaches used in the development of a sensor network or a module for it. As the testing of interconnections between the nodes in IoT networks is of utmost importance for the reliability of the system, the lack of studies is a worrying finding.

The third research question focused on whether specific test methods were used. This research shows that formal software testing was used only in the minority of research. For example, often it was only mentioned that the test cases were passed. Of course, the software parts are small, especially in sensor nodes, but if the developed system has some algorithms to process the gathered data, the software may have several functionalities. These should be tested in some way. One good test is: Will the software perform its functions within acceptable time? Data validation tests were used in a minority of studies. Validation might be important when a system uses the gathered data or the results of processed data in some way.

The results of the RQs raised several new research topic ideas. One possible future research topic that this paper does not analyze in depth is embedded operation systems. There are several types of single board computers on the market and usually each device has its own operating system. These operation systems are mostly Linux-based. An interesting topic would be the variety or modifications of these Embedded Linux components when the target is the increase of processing power.

The second research topic focuses on reliability. The Raspberry Pi based prototypes are usually connected using an experiment board and soldering of connections is not common. This came up from the studies explored. During our previous studies [3], [4] and [5], connection faults were common and it was attempted to prevent them by soldering all possible connections. However, the articles explored in this study did not commonly handle these reliability issues. Only a few of them even mentioned these problems.

Another interesting topic is recovery from faults. When we have noticed that the reliability might be an issue, so we should think about how to recover from the fault and which kinds of faults we could recover. Power failure is one common fault. However, only a few of the studies have handled this situation and the recovery process from power failure. In particular, the Raspberry Pi and its generally used Linux-based operating system are vulnerable to this kind of fault.

These selected studies tested the developed systems in various ways. This research shows the lack of systematic testing procedures of the systems of this kind. If there are systematic ways of testing Raspberry Pi based systems, those were not used. This might be also an interesting future research topic.

V. CONCLUSIONS

This survey showed that the Raspberry Pi is a widely-used device in research implementations of different kinds. The Raspberry Pi is an inexpensive, fully customizable, and programmable credit card-sized single board computer, which supports a large number of peripherals and network communication. Therefor the Raspberry Pi is suitable for small scale prototype testing. In this paper research on sensor network solutions were focused on using a literature review. This paper identified three research questions, which were answered using the systematic literature review approach. The answer of RQ1 showed a lack of formalized approaches, methods, and tools. RQ2 highlighted the minimal use of testing practices and methods, and the third RQ tried to find specific ways of using test methods. Some methods were found: software testing, software performance testing, and validation of data tests. Some further research topics were also identified. These include modifications to the embedded operating system for better performance, reliability, or fault recovery.

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