Northeastern University

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AR - IoT Combo

Project Report

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Abstract

The Internet of Things (IoT) is now an integral part of many different sectors and contexts. It is no longer a tendency, but a real and unstoppable maneuver which is dispatching an army of Internet enabled devices to invade and conquer new territories, and with no signs of retreat. Simultaneously, the scenarios and possibilities for the utilization of Augmented Reality (AR) also keeps expanding. This is a natural result of the technological evolution in multiple sectors, the degree to which industry is embracing it, and the maturity and development of AR-enabling and complementary technologies.

This project is a proof of concept (POC), concretely demonstrating the combined use of AR and IoT in a prototyped "micro production cell" (MPC) environment. IoT devices and components are introduced to support basic operations, and AR apps permit the interaction, monitoring, and control of IoT components. Such interaction is entirely based on the publish/subscribe pattern of the Message Queue Telemetry Transport (MQTT), a lightweight protocol commonly used in IoT environments. The project focuses on "target processes" that are identified and selected to best suit the MPC's characteristics. The AR apps demonstrate different modalities of trackers, starting with marker-based, image-based, 3D model-based, and object detection/recognition alternatives. The first two modalities are mandatory for this POC, other modalities will be evaluated and eventually included, subject to their compatibility to the project's time-frame. The prototype has been deployed in a sequence of complimentary experiments, demonstrating coverage in terms of system's configuration and the menu of features supported by the AR developed apps. The MQTT messages are monitored and analyzed to assess the degree of correctness and efficiency of the resulting solution. This project intends to represent a consistent contribution in evaluating the combined use of AR and IoT technologies.

Contents

1 Introduction

In recent years, IoT has become one of the most important and promising technologies to put together, control, and monitor a huge army of instruments and devices with embedded Internet connections. Everyday objects like appliances, cars, sensors, thermostats, surveillance cameras, production monitors, and etc. are being connected to the Internet through low-cost devices, improving the communication between equipment, people, and processes.

Using specialized protocols to deal with the high volume of data flowing among devices, broker hubs, publishers, and subscribers clients of an always crescent myriad of topics, the IoT is revolutionizing the traffic and the way of exchanging, controlling, and processing data. The figures are impressive, the number of IoT-connected devices are scaling up rapidly. A IHS forecast points to something around 75 billions of IoT worldwide connected devices in 2025, Figure **??**.

Following similar trend, the IoT-generated data volume were expected to reach 52 zettabytes by 2019. Now, in 2021, that volume is projected to reach 85 zettabytes, (Yusuf, 2020).

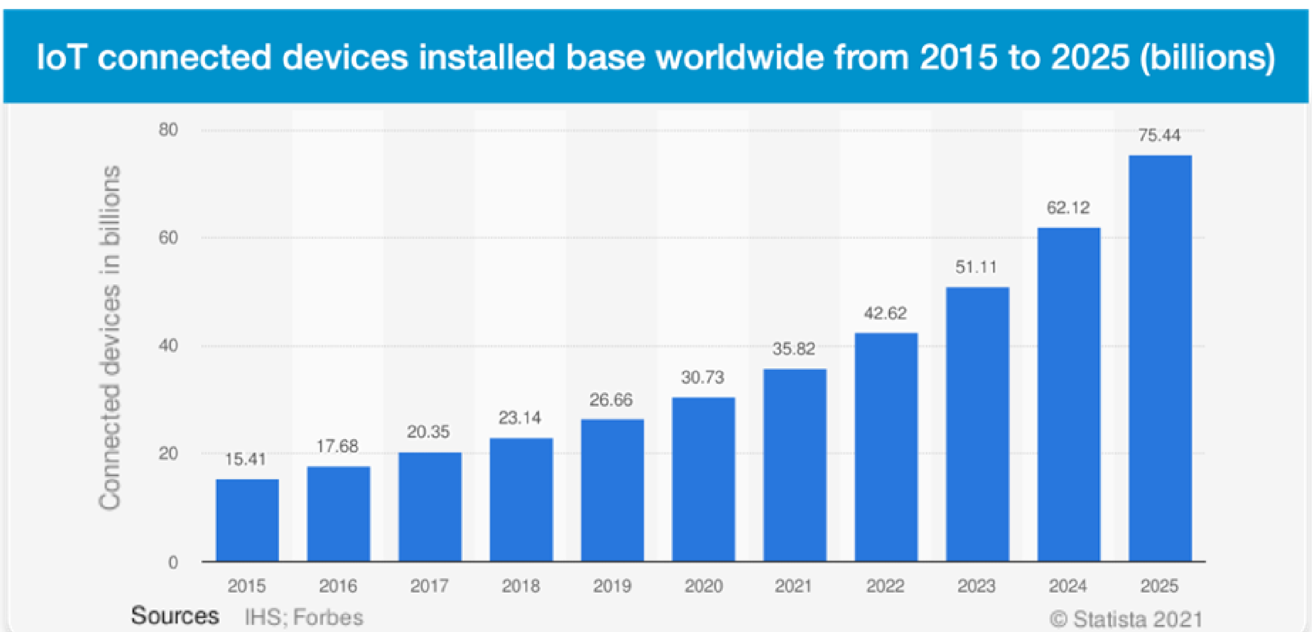

Figure 1: 2015-2025 IoT connected devices. Sources: IHS, at statista.com

Despite the opportunities and excitement surrounding this new scenario, IoT also brings an inexorable challenge: how to deal with the “overdose” of data and info being produced by such an incredible and proliferating population of IoT devices?

Here is one of the most interesting contexts where AR can play a relevant role, with strong appeal to industry operations, marketing, training, and education. Augmented Reality is part of the 4.0 world and together with IoT, and also the contribution of Artificial Intelligence (AI) and Machine Learning (ML), is opening new frontiers, connecting the physical and digital world, revolutionizing the way we respond, control, and manage businesses.

AR IoT can potentialize the power of consuming and processing data through the introduction of virtualized interfaces that overlay digital information on top of the user's physical environment.

This way, AR can be used to handle part of the incoming data and deliver intelligent and proactive directions to users and machine operators, taking the digital data and presenting it back for users to analyze and interact with.

Complementing this scenario, a recent survey revealed another promising tendency: "...more than 80% of companies that are using IoT also use, or are considering using, AR to optimize business operations and reap financial benefits..." (Lukic, 2020). In fact, the numbers are again impressive and reinforce the perspectives of new opportunities on the radar, Figure 2.

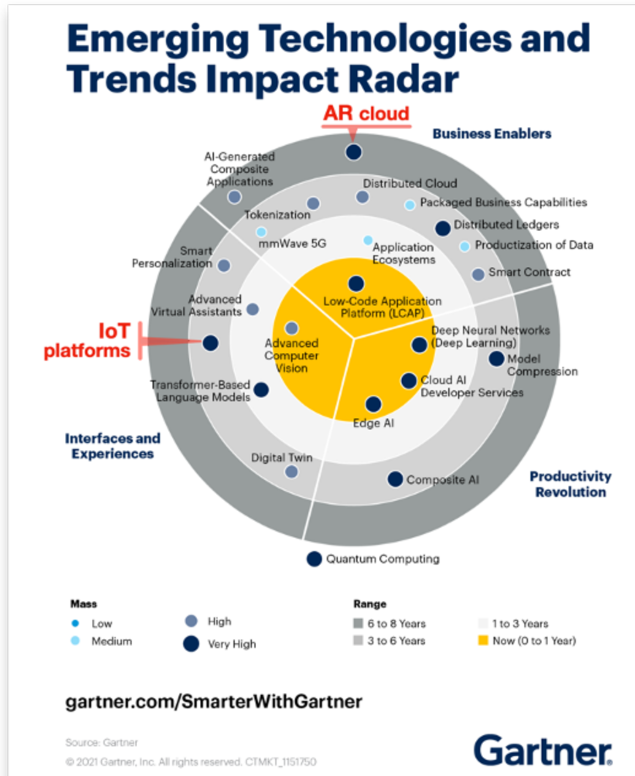

Figure 2: Emerging Technologies Radar. Source: Gartner

2 Context & Opportunities

Considering the exposed panorama, and keeping in mind what has been also forecasted, in a close future, based on the perspectives surrounding IoT and AR technologies, we can identify some important aspects and opportunities:

- IoT is already a reality, and it continues growing really fast
- At the same time, AR is gaining traction and it must be much more than just a gaming thing (and it certainly deserves to be)
- The 5G, and even 6G, latency improvements are just around the corner

With all that in place, the volumes of IoT devices, data, and traffic will escalate even more. In such a context, we believe that it is reasonable to suggest that we are going to need a functional and pragmatic way to deal and interact with such a huge army of embedded devices and data. This perception will also constitute an important driver for the present work.

3 Proposal & Methodology

The current project constitutes a Proof of Concept (POC) study, and it was developed as part of a Capstone project of the MSCS program at Northeastern University. Therefore, in order to attend academic time-frame constraints, this POC has initially adopted a project model based on an accelerated prototype delivery cycle.

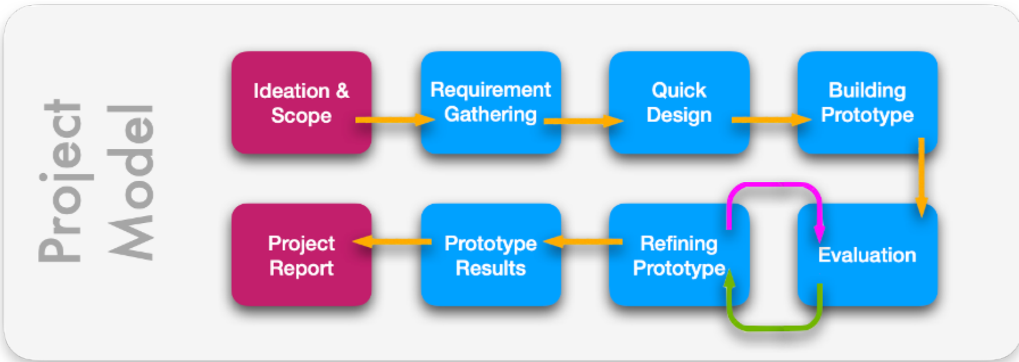

Figure 3: Project Model

Following this prototype cycle workflow, the POC was developed in iteration steps, and delivered in terms of four main and complementary Experiments, which will be covered during the next sections. Regarding its main proposal, the study is committed to offer an alternative formula to integrate AR and IoT, bundled in a non-proprietary and "open-source" based solution (the Combo), and it is oriented to achieve the following objectives and guidelines:

- Use AR as interface between the IoT world and the users, offering an efficient and dynamic solution to monitor and control IoT equipment and other components.
- Support "read & write" operations, what implies in establishing full interaction between AR apps and IoT components. This way, the POC should permit the access, visualization, and modification of operational IoT variables, in addition to the submission of operational commands and the respective monitoring of the affected components' status.
- The integration with IoT devices and data must be as smooth as possible, giving preference to non-proprietary and open-source alternatives, and exploring practices and protocols native to the IoT environment.
- Permit local (on-site) and remote access, supporting marker-based, marker-less, 3D model-based targets, and other AR tracking modalities.
- Focus in attending the business' "target processes".

In essence, the key factor for the present project is to evaluate and promote the discussion about alternative implementations to support "AR – IoT Combo" solutions. This motto can also be stated in a single question:

Can we proof and facilitate the applicability of this AR – IoT combination and, at the same time, make it more accessible and still feasible?

In order to answer this question, we have formulated a roadmap of actions that will be deployed in a sequence of experiments, followed by their results' assessment and evaluation. This roadmap includes:

- Design and implement a prototype environment based on a "micro production cell" (MPC)
- Introduce and configure IoT devices and components to support the basic MPC operations
- Implement Message Queue Telemetry Transport (MQTT) as the main communication and integration protocol
- Develop AR apps to integrate with the IoT environment via MQTT protocol
- Measure and evaluate the MQTT messages volumes and payloads integrity

The Message Queue Telemetry Transport (MQTT) is an open-source lightweight protocol, capable to run over HTTP/IP, that implements a publish and subscribe pattern of communication between the broker (hub server) and its clients (components and devices). It is a very common protocol inside the IoT environment, but a not so usual way of integration into the framework of AR applications.

The project has established MQTT as the main protocol to be used when integrating AR and IoT. This is considered a key and strategic decision in order to fulfill the objectives of this POC, regarding evaluating a non-proprietary solution to put together a functional alternative to connect AR and IoT technologies.

4 Target Processes

During all this project, we have to maintain a pragmatical approach when identifying the candidate use cases to be part of the POC's experiments set. What implies that, whatever AR application we ended up proposing, the solution must offer tangible results and contributions to concrete processes inside the IoT environment.

In other words, during this POC, we have to clearly identify the potential processes which will be the target of our integration solutions. This way, we want to be focused in attending a selection of specific processes and/or operational routines, contributing to better support and enable them by the proposed AR – IoT Combo integrations.

For instance, considering the small sample of potential processes showed in Figure 4, this POC is targeting:

- First moment: Maintenance, Controlling, Tuning & Calibration
- Second moment: Inspection Troubleshooting, Assembling & Disassembling

Figure 4: Target Processes

5 Micro Production Cell

The Micro Production Cell (MPC) is a a very simplified version of a hypothetical production unity. It was idealized to represent an empiric scenario to be used during the project's experiments to implement, test, and evaluate the AR - IoT combination use cases.

Figure 5: The Micro Production Cell (MPC)

How can be observed from the previous image, Figure 5, the MPC is a set of components (a main production equipment, 3D printer, and other devices, servers, software, application, etc.) put together in the same WiFi network.

These components have an important characteristic in common: all of them were configured to "talk MQTTish". That means, we are using the same protocol to interconnect all the MPC components. In order to implement the MPC, we have configured a component to be the MQTT hub (the Broker), and also configured all other components as MQTT clients, what makes them able to publish and subscribe messages on specific topics, previously defined and configured.

5.1 MPC Main Components

- Production equipment: 3D Printer (thiNgator model)
- IoT Devices:
  - Raspberry Pi (3)
  - ESP8266 micocontroller
  - Tello drone
- Message Protocol: MQTT
- MQTT Broker: Mosquitto
- AR & IoT technologies:
  - Unity, Vuforia, WebAR, Arkit
  - Vuforia Spatial Edge Server
  - Vuforia Spatial Toolbox
  - Node-RED
  - Airtable - IoT cloud component
  - M2MQTT - MQTT library
- Others:
  - Sensors and Switches
  - Dedicated router
  - Simplified mechanical arm
  - Object Detection and Recognition (TBD)

6 Assumptions & Constraints

In any real world installation, security is always an important aspect to be considered. In fact, it is very common to observe, usually inside the industrial sector, a complete isolation between the IT network (running ERPs, BIs, Back-office systems and applications, etc.) and the Automation network (running IoT components, PLCs, Supervisory systems, etc.).

However, for simplification reasons, this POC will not be considering security aspects, other than:

- The configuration of an exclusive WiFi component (router, static IPs, DNS, DHPC, etc.) to attend the MPC.
- The use of different AR apps to perform exclusive "read", or exclusive "write" operations

Nonetheless, it's important to emphasize that the MQTT is a kind of client-server system, where we can easily implement identification, authorization, encryption, priorities, messages' life-time, and other security features that have to be obeyed by brokers and clients in order to operate securely and safely.

Regarding the AR development, and for simple availability reasons, the POC is defined to use iOS platform, what implies that all AR code will be built and deployed to run in iPhone devices. A similar set of experiments could certainly be performed in other platforms (Android, for instance).

7 Related Works

We have researched and identified some important initiatives which are also promoting the combined use of AR and IoT technologies. A complete list of consulted sources will be presented later, at the References section of this report.

Here we are going to concentrate in exploring two of the analyzed related works (report papers). These two papers were especially selected by their significant level of intersection and synergy to the present POC's scope.

For the sake of brevity, we will provide a simplified and schematic overview about the papers in question. More complete and detailed versions can be obtained accessing their informed sources.

7.1 Paper 1: Augmented Reality with Internet of Things

- Proposal: To describe the concept of how Augmented Reality can be integrated with industry (AR-IoT) 4.0, presenting how the sensors are used to monitor objects/things contiguously round the clock, and discussing the process of converting real-time physical objects into smart things for the upcoming new era with AR-IoT.
- Results: IoT has now acquired a unique impact between industries. The inclusion of the AR feature to IoT enlarges its capabilities. In the industrial maintenance workflows, industrial IoT technologies are now evolving AR technology, where digital duos and other IoT sensors anticipate possible problems on a manufacturing system and on local workers.

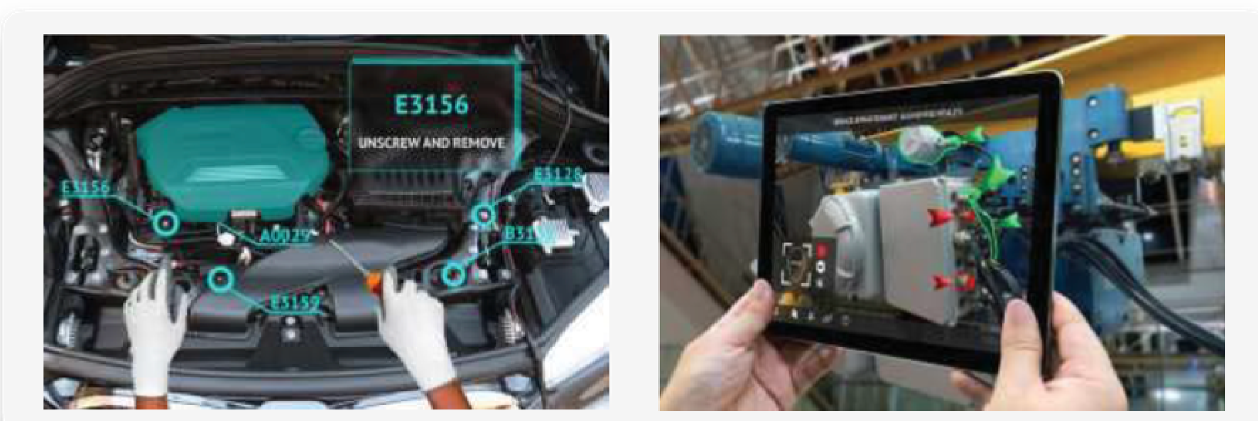

Figure 6: Project 1: AR used to support maintenance and troubleshooting processes

- Highlights:
  - The paper is a conceptual discussion which proposes and stimulates the use of AR IoT mix (ARioT) to leverage the industry 4.0 and transform real-time physical objects into empowered smart things.
  - IoT: a conduit between physical infrastructure and remote infrastructure.
  - AR: facilitates digital interaction in real time with the physical world.
  - Potential gains when applying the ARioT mix in manufacturing: Boosting Revenue; Creating Strategic Value; Reducing Costs.
  - 80% of surveyed companies expect AR-IoT solutions to become day to day routine.
  - The paper explores the concepts about ARIoT and defines its main components.
- Source: S. Sureshkumar, C. P. Agash, S. Ramya, R. Kaviyaraj and S. Elanchezhiyan, "Augmented Reality with Internet of Things," 2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS).

7.2 Paper 2: MagicHand - Interact with IoT Devices in AR Environment

- Proposal: Create immersive AR-IoT interactions to improve the way smart devices are controlled via more direct visual feedback. Develop a functional Ar-IoT prototype, enabling seamless interactions with sound and lighting systems through the use of augmented hand-controlled interaction panels.
- Results: User study shows that the system increased interaction speed and satisfaction level. Quantitative evaluation results show that the solution can achieve high hand gesture recognition accuracy, and detect and localize target devices accurately within a proper working range.

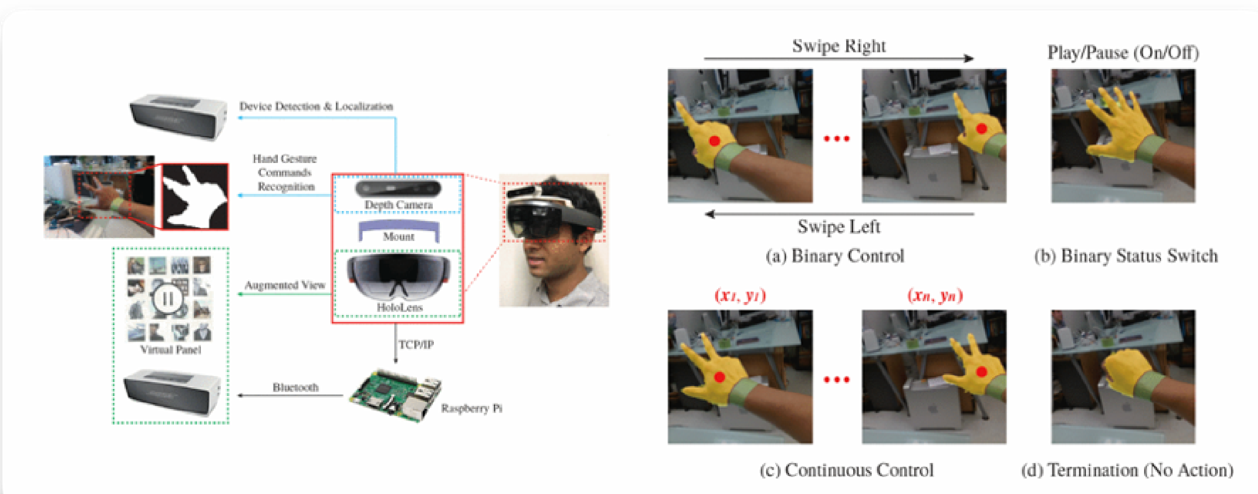

Figure 7: Project 2: AR supporting gesture-based recognition processes

- Highlights:
  - The project is a Proof of Concept where the main idea is to implement a system that allows seamless interaction with IoT devices in an immersive AR environment, comprehending:
    * Automatic device detection for rapid user-device interaction and initialization.
    * Instance-aware holographic panels for visual feedback during interaction.
    * A gesture-based seamless interface for device control.
  - The prototype includes a depth camera, Raspberry Pi and HoloLens, allowing users to interact and control sound and lighting systems with gestures.
  - Uses TensorFlow Python API and CNN to construct and train the model and recognition.
  - Integrates using a proprietary TCP/IP based protocol.
  - The paper conducts a user study comparing user control experience between the proposed solution and commercially available applications.
- Source: Y. Sun, A. Armengol-Urpi, S. N. Reddy Kantareddy, J. Siegel and S. Sarma, "MagicHand: Interact with IoT Devices in Augmented Reality Environment," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR).

8 The Experiments

This section will be covering a set of four experiments which we have developed in order to test and evaluate different aspects related to the AR - IoT Combo solutions' feasibility.

The experiments were realized in a chronological order, considering their crescent level of complexity and interdependence, being the former experiment a preparatory step for the subsequent one.

As an initial procedure, we have defined specific IoT variables to be monitored and modified during the experiments. In this case, we are using the Nozzle Extruder Temperature and the Bed Temperature variables as targets of our project's experiments, Figure 8. Both variables are very peculiar inside 3D printing operational routines, once they have to be constantly checked and modified in order to start producing 3D objects, directly affecting the printer resulting performance, and also impacting on the quality of printed pieces.

MPC sensors/variables that will be monitored ("read") and modified ("write")

Variable	MQTT Topic
Nozzle Extruder temperature	thiNg/temperature/tool0
Bed temperature	thiNg/temperature/bed

Figure 8: The MPC monitored & modified variables

In the first moment, the AR applications are using the image-based tracking modality to trigger the insertion of virtual objects in the scene presented by the AR interface, Figure 9

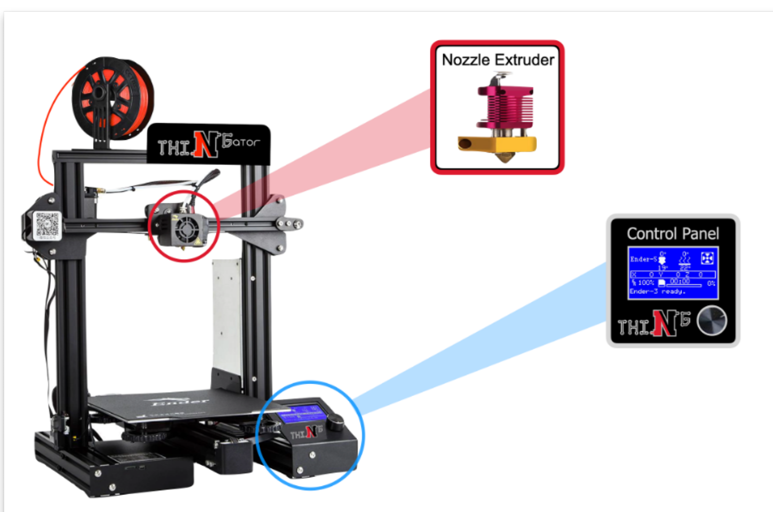

Figure 9: AR image-based trackers used to access the Nozzle Extruder and Bed temperature values

8.1 Experiment 1: Connecting IoT Components via MQTT

This experiments is a foundation step, configuring the MQTT system to fully operate inside the MPC, and displayng the IoT selected variables in a dashboard panel. This step will also be preparing the base for the next experiments.

Figure 10: Experiment 1: Connecting IoT Components via MQTT

8.2 Proceedings

- Components:
  - One 3D Printer (thiNgator): running Marlin
  - One Raspberry Pi: running Mosquitto, OctoPrint, and Node-RED
  - One laptop computer: running browser-based Node-RED dashboard
- Tasks:
  - Install and configure Mosquitto open-source MQTT broker (to act as the MQTT main hub inside the MPC).
  - Install and configure 3D printer using Marlin open-source firmware (to manage all the real-time activities of the machine).

– Install and configure OctoPrint open-source 3D printer controller and API.

– Install and configure Mosquitto open-source MQTT broker (to act as the MQTT hub inside the MPC).

– Install and configure Node-RED open-source programming tool (to connect to IoT components via MQTT)

– Configure MQTT topics to support publish and subscribe operations to access the selected temperature values.

– Configure and code Node-RED flows to capture the temperature variables and present them in a dashboard browser-based application

8.3 Results

After implementing the required proceedings, the Node-RED dashboard has correctly presented the Nozzle Extruder and Bed temperatures values in real-time, reflecting all eventual temperature fluctuations occurred to the variables inside the IoT environment, Figure 11.

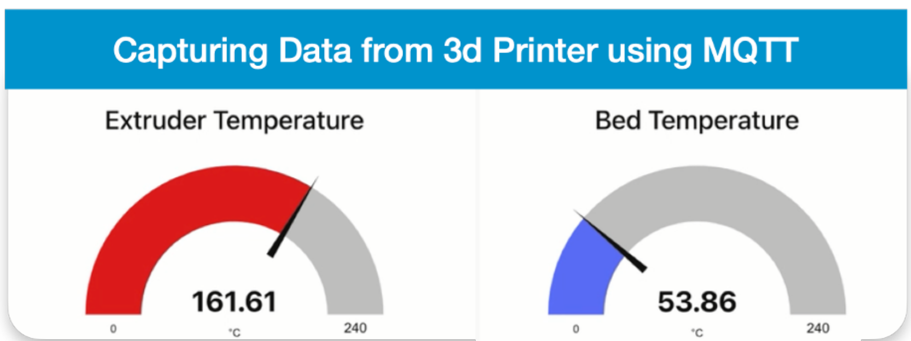

Figure 11: Experiment 1: MPC temperature variables presented in real-time in a Node-RED dashboard

8.4 Experiment 2: Integrating AR IoT (MQTT through cloud dataset)

This experiment includes, for the first time, an AR application integrated to IoT data. In this case, we will be using a cloud dataset as an intermediary stage between the IoT environment and the AR app. The Node-RED code will be monitoring the MPC variables via MQTT. When the temperature values present a variation equal or greater a previously configured threshold (in this case, set to +/- 0.1 °C), these values will be immediately updated in an Airtable component (a cloud dataset, commonly used in IoT integrations). Simultaneously, an AR application using Vuforia Toolbox will be continuously reading the cloud dataset and presenting the temperature values in a counter and in a graph component, which are being displayed inside the AR app.

Figure 12: Experiment 2: Integrating AR & IoT (MQTT through cloud dataset)

8.5 Proceedings

- Components:
  - One 3D Printer (thiNgator): running Marlin
  - One Raspberry Pi: running Mosquitto, OctoPrint, and Node-RED
  - One Raspberry Pi: running Node-RED, Vuforia Spatial Edge Server
  - One iPhone: running the Vuforia Toolbox app

- Tasks (only the additional ones will be listed):
  - Install and configure Vuforia Spatial Edge Server open-source distributed edge infrastructure (to connect the Vuforia Toolbox app to physical objects, machines, and processes).
  - Configure Airtable free version (platform for building collaborative apps in the cloud).
  - Install and configure Vuforia Toolbox open-source AR app (to enable visualization and interaction with data and logic provided by the Vuforia Spatial Edge Server).

8.6 Results

After implementing the required proceedings, the Node-RED has correctly updated the Airtable intermediary cloud dataset. In the sequence, the AR Vuforia Toolbox application has correctly accessed the cloud dataset and displayed the Nozzle Extruder temperature value in real-time, reflecting all eventual temperature fluctuations occurred to the variable inside the IoT environment, Figure 12.

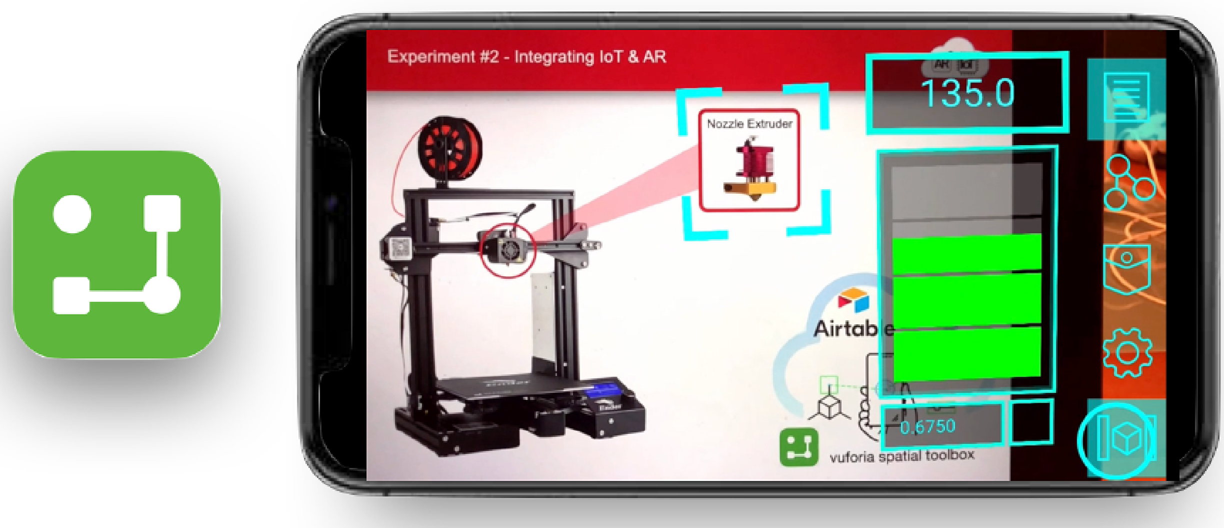

Figure 13: Experiment 2: MPC Nozzle Extruder temperature presented in real-time in a Vuforia Toolbox AR app

8.7 Experiment 3: Integrating AR IoT (MQTT enabled AR app)

This experiment includes, for the first time, an MQTT enabled AR application integrated to IoT data. The AR app was transformed in a true MQTT client, and it is using the **subscribe** messages to access the MPC variables in real-time, permitting their visualization inside the AR interface. This way, we have a direct integration between the AR and IoT environments via MQTT. At this point, the experiment delivers a "read-only" version of the AR app. No modifications in terms of variables' values, or even remote commands were implemented.

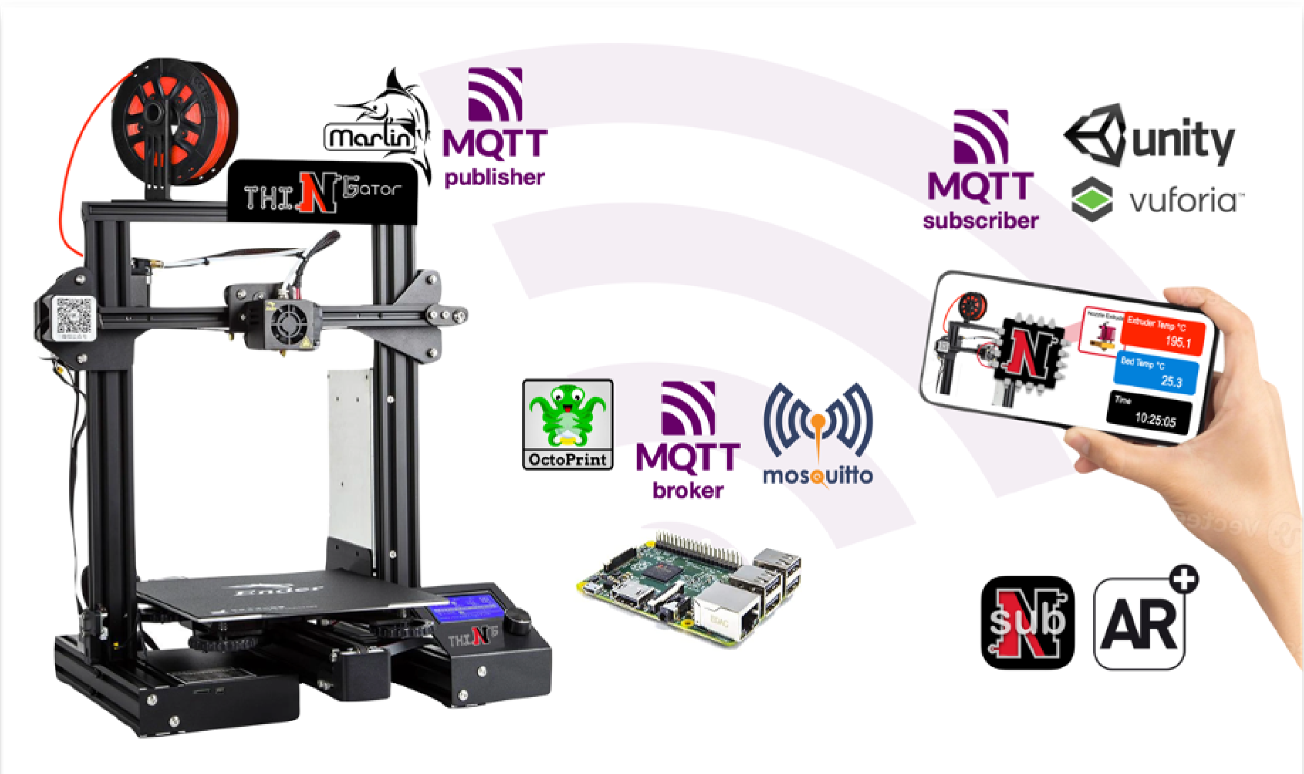

Figure 14: Experiment 3: Integrating AR IoT (MQTT enabled AR app)

8.8 Proceedings

- Components:
  - One 3D Printer (thiNgator): running Marlin
  - One Raspberry Pi: running Mosquitto, OctoPrint
  - One iPhone: running the Unity Vuforia AR app
- Tasks (only the additional ones will be listed):
  - Install and configure Unity and Vuforia free versions for XR/AR development (to develop AR apps).
  - Install and configure M2MQTT open-source library (to enable AR via MQTT apps using **subscribe** messages)

8.9 Results

After implementing the required proceedings, the AR app was able to connect to the IoT environment via MQTT, acting as a client, and using **subscribe** messages. This way, the AR app has correctly accessed and displayed (read-only) the Nozzle Extruder and Bed temperature values in real-time, reflecting all eventual temperature fluctuations occurred to the variables inside the IoT environment, Figure 15.

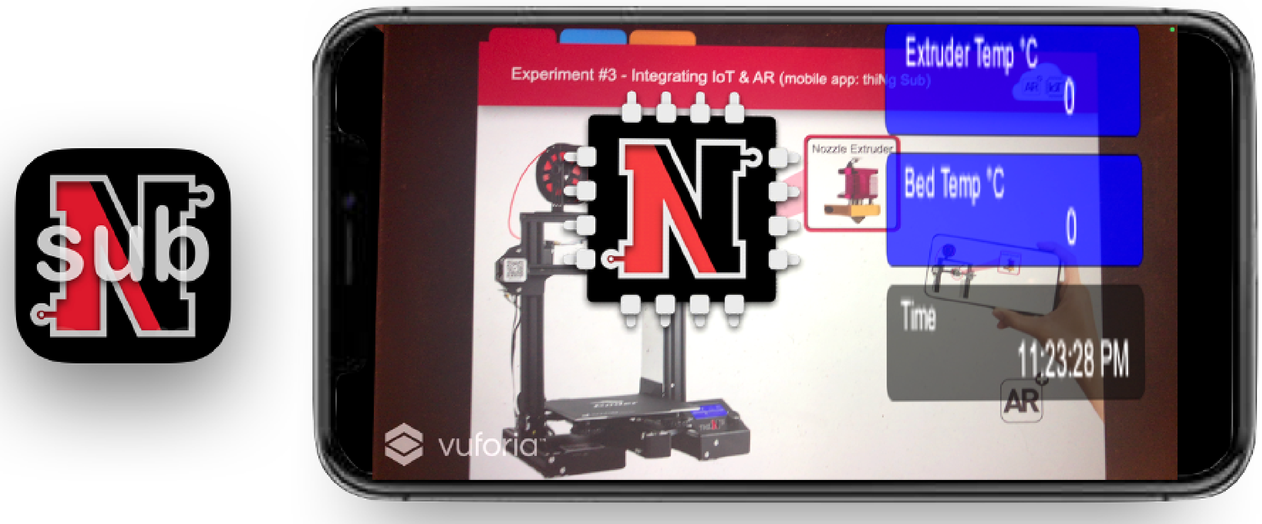

Figure 15: Experiment 3: MPC Nozzle Extruder and Bed temperatures presented in real-time using a MQTT enabled AR app

8.10 Experiment 4: Integrating AR & IoT (full interaction - read & write support)

This experiment includes, for the first time, an MQTT enabled AR application with full integration to IoT data. The AR app was transformed in a true MQTT client, and it is using the **publish** messages to send commands to the IoT environment and modify the MPC variables in real-time, using virtual buttons inside the AR interface. This way, we have a direct integration between the AR - IoT environments, via MQTT, and with full control (enabled to read and write IoT variables). At this point, the AR app has implemented the following buttons/commands:

- Preheat - to initiate a 3D printer preheating routine for both, Nozzle Extruder and Bed temperature
- Cooldown - to bring the Nozzle Extruder and Bed components to ambient room temperature
- Print - to send a file (in this case, the thiNg file) to be 3D printed

Figure 16: Experiment 4: Integrating AR & IoT (full interaction - read & write support)

8.11 Proceedings

- Components:
  - One 3D Printer (thiNgator): running Marlin
  - One Raspberry Pi: running Mosquitto, OctoPrint
  - One iPhone: running the Unity Vuforia AR app

- Tasks (only the additional ones will be listed):
  - Install and configure M2MQTT open-source library (to enable AR via MQTT apps using publish messages)

8.12 Results

After implementing the required proceedings, the AR app was able to connect to the IoT environment via MQTT, acting as a client, and using **publish** messages. This way, the AR app has commanded Preheat, Cooldown, and Print routines straight to the MPC 3D printer, inside the IoT environment. The 3D printer has correctly received the command and started the respective routine with success, Figure 17 and Figure 18.

Figure 17: Experiment 4: AR app presents interface buttons and sends respective commands to the IoT environment

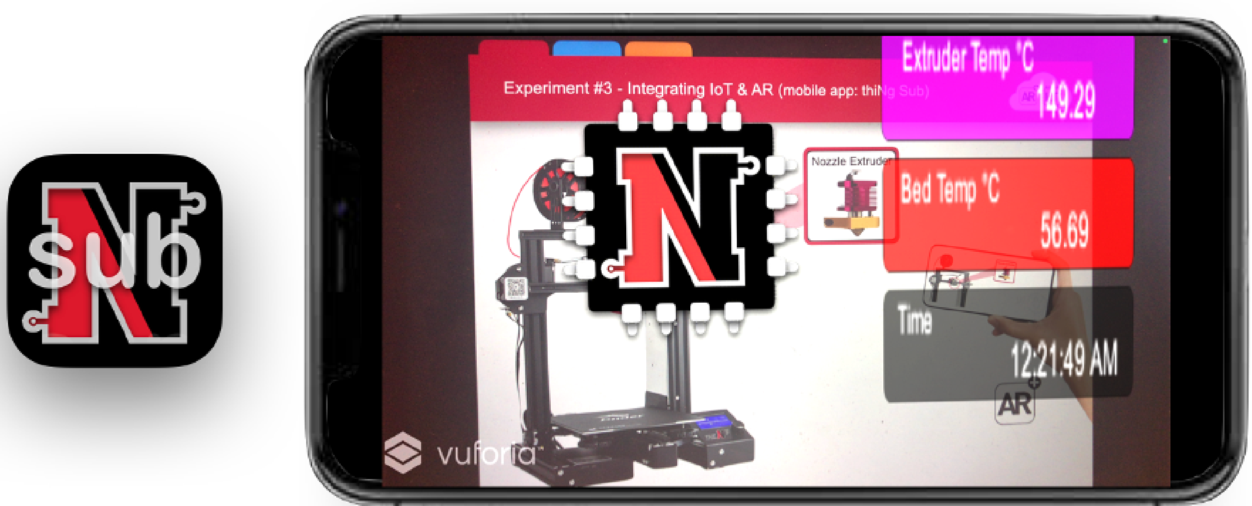

Figure 18: Experiment 4: AR app presents the Nozzle Extruder and Bed temperature values in real-time, reflecting changes commanded by a previous click of the Preheat button

9 Results & Conclusions

This section will summarize the main finds and conclusion observed when developing this POC, and the the results and impressions obtained during the implementation of the previously described sequence of experiments.

- MQTT Spy software was used to inspect the flow of MQTT messages, their volumes, statistics, and the consistency of payloads, Figures 19 and 20.
- All messages were Published and Subscribed as expected, resulting in an efficient way to connect IoT devices to different interfaces (Node-RED, Vulforia Toolbox, AR apps, etc.)
- Local and remote access to the IoT devices were performed accordingly, with all defined experiments having achieved the proposed objectives.
- The selected MPC variables (Extruder and Bed temperature) were correctly accessed, displayed, and modified during the experiments, Figure 21.
- The POC has strongly confirmed the applicability of MQTT protocol in supporting and enabling AR and IoT integration.
- The POC has also confirmed that AR can certainly be used in conjunction with IoT as a functional and reliable interface to respond to crescents volumes of internet embedded devices and associated data being produced.

The implementation and evaluation of all the exposed methodology, experiments, and results make us confident to answer the key question previously formulated at section 3 of this report. All that considered, we have converged to the following conclusion:

YES, the AR - IoT Combo is feasible, responsive, and reliable.

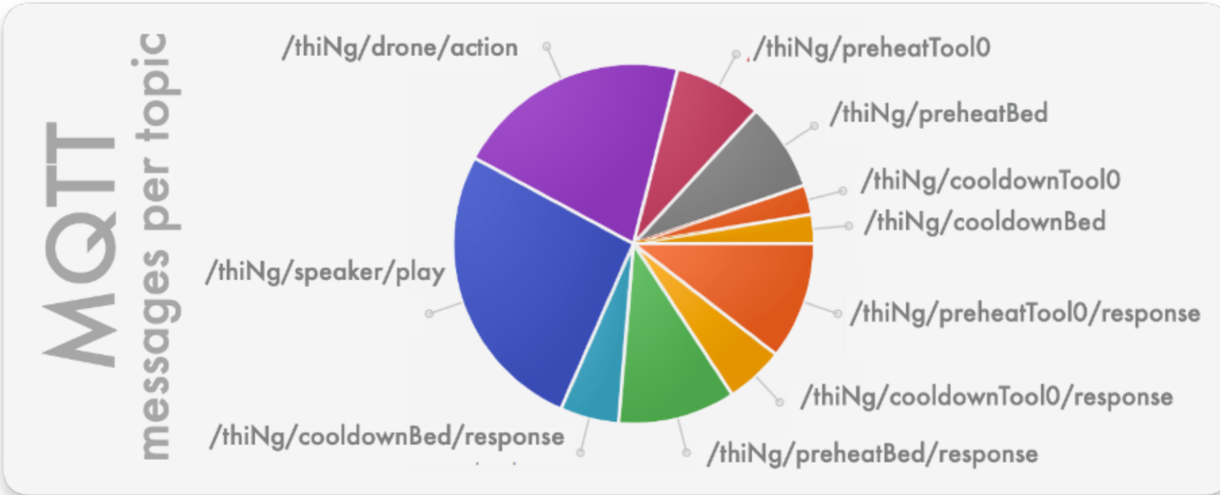

Figure 19: MQTT messages volumes per processed topics

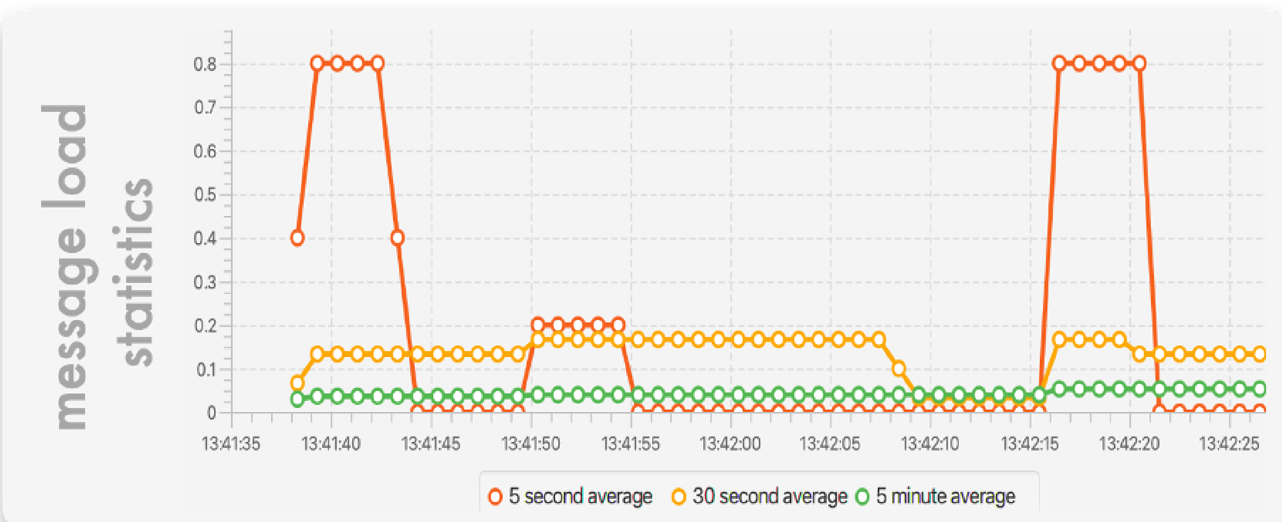

Figure 20: Message load statistics

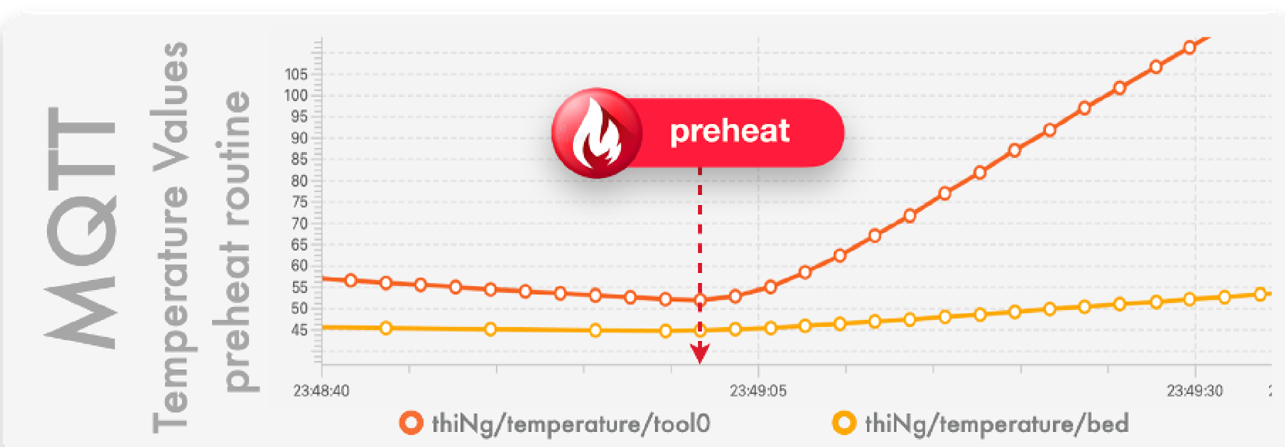

Figure 21: MPC temperature variables increasing just after the Preheat button being pressed

10 Future Work

There are additional experiments and additions we would like to incorporate to the present work. Here we will be mentioning the ones which we have already initiated, and some other initiatives that are in our radar to be implemented in a brief future:

- Develop scripts (MQTT Spy) to simplify and standardize MQTT flows' tests and evaluations.
- Incorporate new AR - IoT Experiments:
  - Tracking based on 3D and CAD models.
  - Tracking based on Object Detection (on the way).
  - Control a simplified robotic arm (on the way).
  - Object Recognition (using drone's camera) to support Inspection/Troubleshooting.
- Implement security additional features: clients identification & authorization, message encryption, etc.

11 References

[1] S. Sureshkumar, C. P. Agash, S. Ramya, R. Kaviyaraj and S. Elanchezhiyan, "Augmented Reality with Internet of Things," 2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS), 2021, pp. 1426-1430, doi: 10.1109/ICAIS50930.2021.9395941.

[2] Y. Sun, A. Armengol-Urpi, S. N. Reddy Kantareddy, J. Siegel and S. Sarma, "MagicHand: Interact with IoT Devices in Augmented Reality Environment," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), 2019, pp. 1738-1743, doi: 10.1109/VR.2019.8798053.

[3] L. Priyan, M. G. M. Johar, M. H. Alkawaz and R. A. A. Helmi, "Augmented Reality-Based COVID-19 SOP Compliance : Social Distancing Monitoring and Reporting System based on IOT," 2021 IEEE 12th Control and System Graduate Research Colloquium (ICSGRC), 2021, pp. 183-188, doi: 10.1109/ICSGRC53186.2021.9515234.

[4] T. -H. Wang et al., "The management control system for plant factory that uses the IoT technology in combination with Augmented Reality technology," 2020 International Symposium on Computer, Consumer and Control (IS3C), 2020, pp. 1-4, doi: 10.1109/IS3C50286.2020.00007.

[5] Yusuf, Zia. "Unleashing the Power of Data with IoT and Augmented Reality", btc.com, https://www.bcg.com/en-ca/publications/2020/unleashing-the-power-of-data-with-iot-and-augmented-reality. Accessed 30 Jul 2021.

[6] Nguyen, Tuong. "4 Impactful Technologies From the Gartner Emerging Technologies and Trends Impact Radar for 2021", Gartner, https://www.gartner.com/smarterwithgartner/4-impactful-technologies-from-the-gartner-emerging-technologies-and-trends-impact-radar-for-2021/. Accessed 29 Jul 2021.

[7] Lukic, Vladimir. "Combining IoT and Augmented Reality for Business Continuity and Transformation". MIT-Sloan, https://sloanreview.mit.edu/sponsors-content/combining-iot-and-augmented-reality-for-business-continuity-and-transformation/. Accessed 01 Aug 2021.

[8] Rosencrance, Linda. "Using IoT Augmented Reality to Enhance Workplace Operations" IoT World Today, https://www.iotworldtoday.com/2021/03/23/using-iot-augmented-reality-to-enhance-workplace-operations/ Accessed 18 May 2021.