NeoCam Technical Report

Version: 1.0

NeoCam: An edge-cloud platform for non-invasive real-time monitoring in neonatal intensive care units

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Contents

1 Overview

This technical report is supplementary material for the paper

NeoCam: An edge-cloud platform for non-invasive real-time monitoring in neonatal intensive care units.

While the paper describes clinical related aspects and AI-based algorithms used to measure clinical parameters, this report focuses on the technical description of the platform. This technical report is more suited towards an audience of software engineers and developers, and it contains all the necessary information to replicate the entire platform, including links to open-source code repositories, and videos from demonstration of use in real situations.

From a software development/engineering perspective, NeoCam is described following a **4+1 architectural view**, describing the entire platform through different UML-based diagrams, with the aim to help and assistant software engineers in the understanding and replication of NeoCam. This is detailed in Section 2.

In terms of hardware and assembling, and with the aim to assist electronics engineers, the core element of the platform (NeoCam Unit) is also described in detail. The NeoCam Unit is an edge-oriented computing device with embedded recording features along with AI-based algorithms to capture and process video in real-time. The tasks performed by this unit involve measuring motor activity, breathing rate, pose and emotional status of the neonates. The technical reports include description about the different hardware components (see Section 3).

In order to test the NeoCam platform in a Proof of Concept, an Android-based mobile application was developed to integrate the different functionalities and services provided by the platform. The mobile app is the end-point for end-users (healthcare professionals and relatives). The application enables the remote monitoring of infants and shows the capabilities of the NeoCam platform through a friendly, informative front-end. The features of the application as well several snapshots can be found in Section 4.

Finally, the resources required to design, assemble and implement any aspect related to NeoCam can be found in the repositories listed at the bottom of this document (see Section 5).

2 System Design

NeoCam has been conceived as a telemonitoring solution with the following features:

1. **Decentralized Computing**. NeoCam is based on a network of camera units (NeoCam Unit) located on incubators that not only send video for streaming but also high-level information that results from processing the video with AI algorithms to the cloud, through an hybrid connection approach (4G/5G + WiFi). This avoids further processing in the cloud infrastructure, reducing the computational load and enabling the set up of several NeoCam units in the same scenario. This solution favours scalability and minimizes potential performance issues that may appear when many end-node devices are used simultaneously, as video requires a high bandwidth.

2. **Embedded hardware**. The NeoCam Unit, as edge-computing device, minimizes cabling and facilitates its installation in the crowded environment of a NICU. It is an all-in-one device with cameras and visual processing units (VPUs) that implement efficient machine learning and computer vision algorithms in the same device at high frame speed.

3. **End-user-oriented solution**. The system is designed considering the services that must be provided to end-users (e.g. healthcare professionals and relatives): real-time monitoring, proper visualization of the information, notifications in case abnormal infant's health state, video streaming etc. The services and functionalities provided by NeoCam can be consumed through a friendly Android-based mobile application.

4. **Non-Proprietary Software/Hardware**. The system is open-source and hardware is based on commercial components that can be easily purchased. In addition, the required software, design schemes, machine learning trained models and the rest of source code required to replicate NeoCam platform are available in the repositories that can be found in the *Repository* (see Section 5).

2.1 Architecture of NeoCam

NeoCam platform consists of several software components and hardware devices that support the different functionalities required to provide the non-invasive monitoring service for infants. In order to describe the main components of NeoCam, we make use of the *4+1* architectural view model. The 4+1 architectural view model describes any software system, using four different views to represent its design: logical, process, physical and development views (see Figure 1).

The *4+1* model is preferred in this work to describe NeoCam because it enables software engineers and developers to learn the system from different practical points of view, linking design with implementation. In this sense, NeoCam could be reused along with the released source code available at *Repository* (see Section 5) to solve similar problems, and the services provided could be adapted and applied in other systems designed for similar purposes.

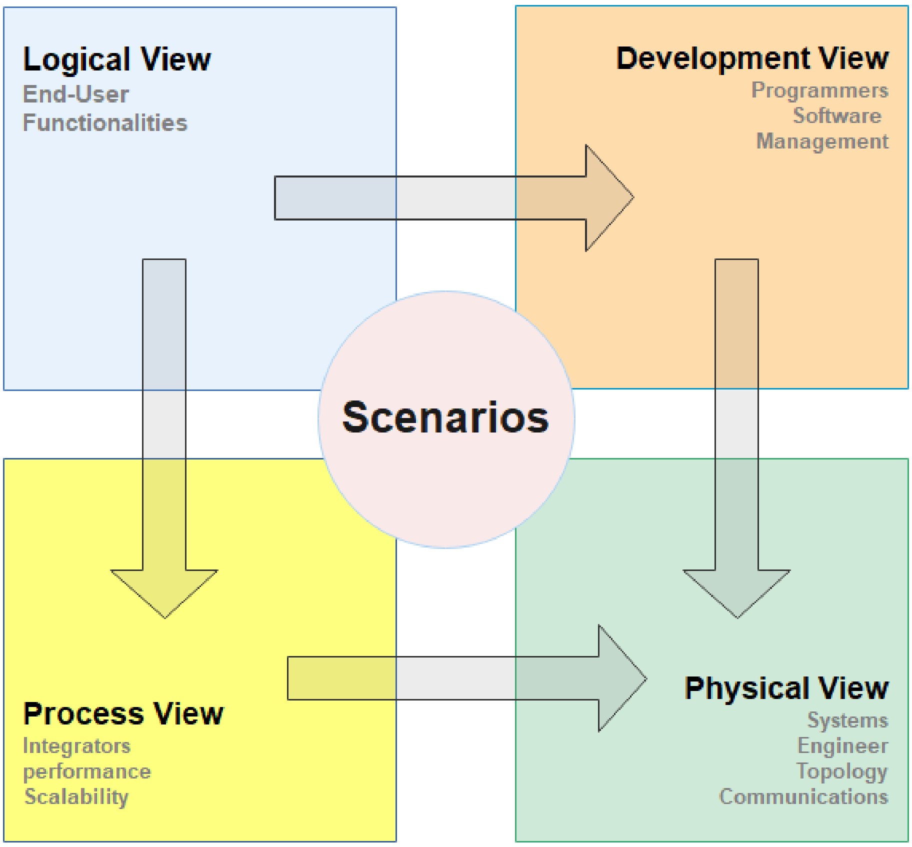


Figure 1: The 4+1 View Model

2.2 Logical View

The logical view captures the functionalities provided by NeoCam to its end-users (e.g., healthcare professionals, nurses, doctors, relatives). Most NeoCam functionalities are served in the mobile application, (see Section 4). However, many others are implemented in the back-end as core services to the entire platform, providing functionalities to end-users but also to the proper functioning of the system.

The different services (functionalities) and service consumers (end-users) of the NeoCam platform have been represented in the layered-oriented architecture shown in Figure 2, which consists of three layers: *1)* care service layer; *2)* monitoring service layer; and the *3)* image data acquisition, communications and computing layer.

The care service layer is directly connected to professional healthcare facilities, staff and relatives, such as hospital, NICU nursing team, other healthcare professional and parents. Through the NeoCam platform, healthcare professionals can monitor in real-time, anywhere and anytime the state of the infant through a real-time live streaming, and access certain physiological and behavioral parameters. In addition, NeoCam allows issues notifications in case an infant is stressed, the breathing rate is above or below certain thresholds or the level of activity is abnormal.

The monitoring service layer works as a bridge between the other two layers, providing services related to the non-invasive monitoring of physiological parameters and the real-time notification system. This layer also serves as an efficient way to supervise in real-time infants through a streaming service. This layer has the following functions:

1. **AI-based services for non-invasive monitoring**. Machine Learning techniques are used in NeoCam to detect infants' parameters from non-invasive techniques to gather information (video/images captured by the camera device). The NeoCam platform allows to measure the emotional status (stressed or not stressed), the level of motor activity and the breathing rate of the infants.

2. **Real-time monitoring services**. The permanent monitoring of infants is crucial. Thus, the NeoCam platform supports this constant monitoring through three different services: *1)* a live streaming service that allows healthcare professionals or relatives to watch the baby at any time and anywhere; *2)* a publish/subscriber notification service to send real-time notifications to the care service layer whenever required; and *3)* the possibility to retrieve at any moment the current infant's parameters values (emotional status, level of motor activity and breathing rate).

3. **Data processing and management services**. The flow of data between the care services and capturing services sometimes requires storage in case a post-processing stage is required. The NeoCam platform is supported entirely by cloud-based technology, which exploits the cloud benefits in the data processing and storing, which amount mostly to scalability, limitless space and permanent access to the information.

The image/video acquisition service layer includes the devices and functionalities related to the acquisition or gathering of information. In addition, since NeoCam

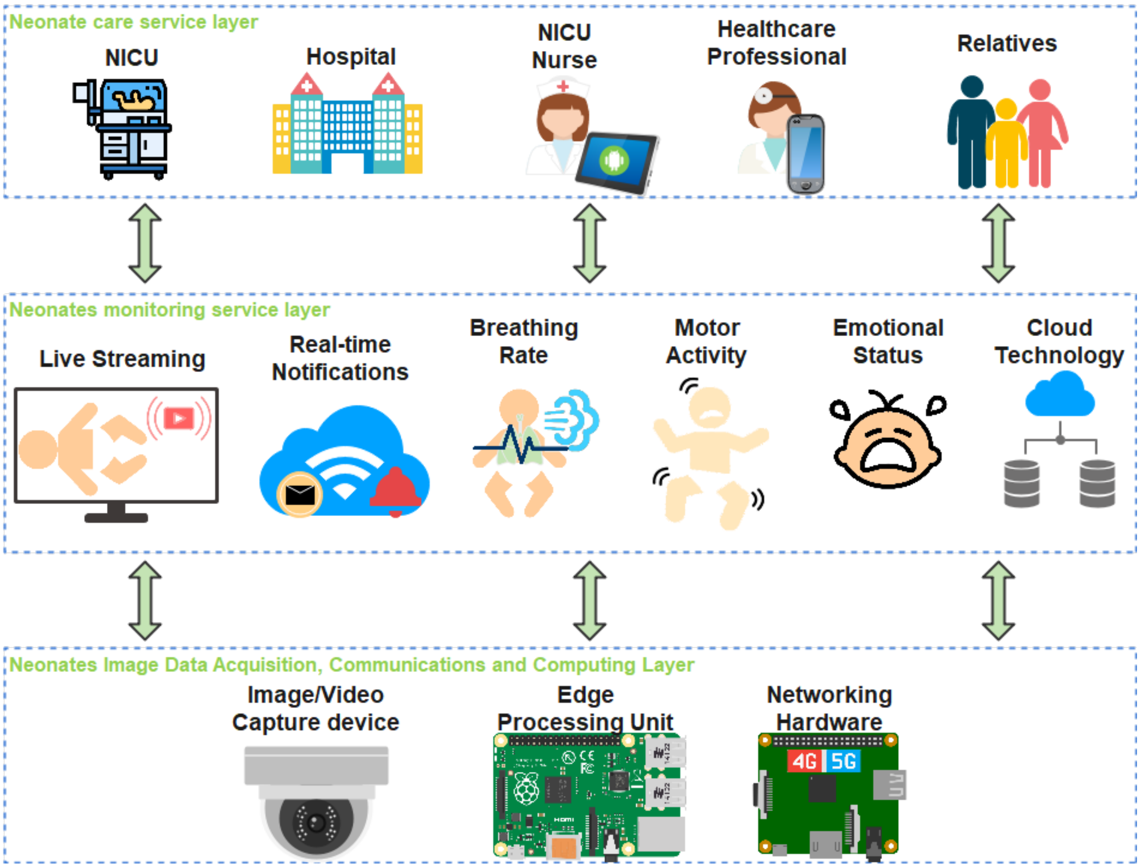


Figure 2: NeoCam Logical View

is edge-computing oriented, the main core of the data processing is carried out in this layer. The main core data type used in NeoCam is the video, which provides different services related to the capture of images and the processing of these images as main input for the AI-based and real-time monitoring services, which are consumed by the care service layer.

In addition, since constant monitoring/supervision is a cornerstone in any telemonitoring system, NeoCam implements a hybrid access network which is composed of two different types of networks: a Wireless Local Area Network (WLAN) based on WiFi and a Cellular Network. In case WLAN were not working properly or in case it is not supported in the NICU Hospital, NeoCam can also use Cellular Networks (4G/5G), which are broadening and can be accessed anywhere and anytime.

2.3 Process View

This view addresses the processes of NeoCam and how they communicate, i.e., the different steps carried out to monitor infants by end-users. Figure 3 depicts an UML-based activity diagram to represent the different processes of NeoCam platform.

The procedure to monitor infants in NeoCam is a sequential set of processes, starting from the image/video recording and concluding with the visualization of the infant (real-time streaming) or physiological information (charting/plotting).

The recording device captures frame by frame and sends them to the streaming server, supported by the cloud-based back-end. At the same time, a subset of these frames are used to obtain the infant's parameters (respiration or breathing rate, the stress level and the motor activity). These values are obtained using machine learning algorithms and computer vision.

These infant's parameters are sent to the cloud-based back-end, which are stored in the system database and checked in case some of them are considered abnormal, that is, whether their values lie within the ranges specified by healthcare professionals. Infant's values are sent to the end-users (healthcare professionals, relatives), but in case an abnormal value is detected, a customized notification is additionally sent to the end-users. In parallel, in this same group of processes, the streaming is sent to the end-users to allow the real-time visualization of the infant.

Finally, the end-users, through the mobile application, are able to visualize the infant through the streaming service, review notifications and infant's parameters, depicted as plots and customized lists of values in real-time. In addition, the end-users can access historical records and obtain aggregated statistics and comparison of the baby's behaviour and evolution.

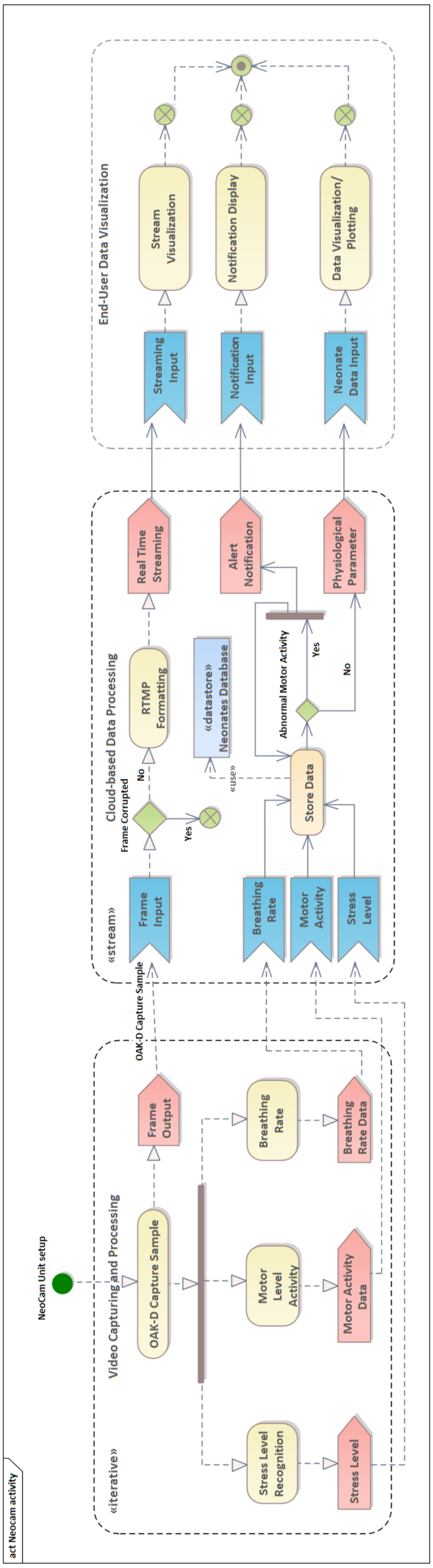


Figure 3: NeoCam Process View

2.4 Physical View

From a system engineer's point of view, NeoCam is composed by:

1. **NeoCam Unit**. Described in Section 3, NeoCam Unit is an all-in-one device used to *1)* record the infant, *2)* obtain the physiological values through a Machine Learning-based approach and, finally, *3)* send the information (streaming and data) to the cloud before sending it to the end-users.

2. **Cloud-based back-end**. Most functionalities are implemented as a service and deployed in Azure®Infrastructure, supported by Microsoft®. The back-end, and therefore the different services, are used by the NeoCam Unit to upload information, and the mobile application consumes these services to get information, receive notifications or stream real-time video and retrieve historical data.

3. **Mobile Application**. The Android-based application, decribed in Section 4, provides a front-end or Graphic User Interface (GUI) to healthcare professionals (nurses, doctors) and relatives (parent, tutors) to access the different monitoring-related functionalities provided by the NeoCam platform.

Figure 4 provides an overview of the entire NeoCam platform and the relations between the three elements.

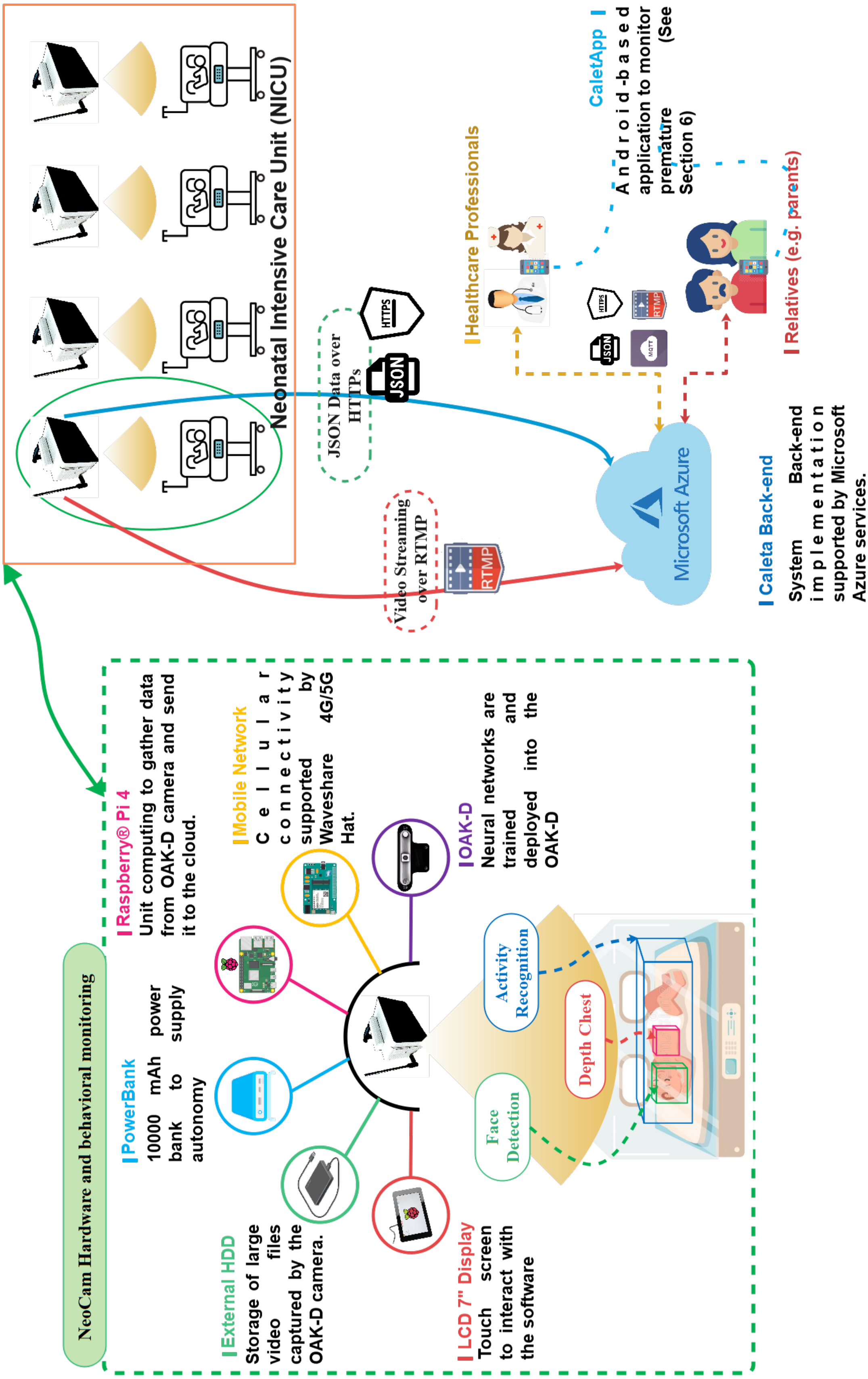


Figure 4: Physical View of NeoCam

2.5 Development View

In the *4+1 view model*, the development view illustrates a software perspective of the different devices and artefacts, in order to help programmers, developers and software engineers to understand the internal software structure with the aim to assist them in the replication of the NeoCam platform.

Most of NeoCam platform functionalities have been developed following a Component-Based Software Development (CBSD) approach. Each component focuses on a specific concern of the system to provide a set of functionalities, such as management of RTMP data, HTTP connections, application of machine learning techniques and data dissemination, among others.

Following a CBSD approach it is possible to reuse a specific software component in a different system or to add new functionalities to a specific software without affecting the rest of the software components, enhancing not just the extensibility and reusability but also the maintenance of the system.

The use of CBSD to design and implement a system as independent modules is very common in software engineering projects, due to its features such as re-usability, ease of adoption and encapsulation, among others.

On the other hand, other functionalities have been implemented as a service, based on the principles of a Service Oriented Architecture. These functionalities have been implemented as web services consumed through a RESTful API, in order to support the use of these functionalities by any device or software, regardless of the platform or technology.

Figure 5 depicts the architecture of NeoCam, illustrating the different artefacts, components, services and the interactions between them. The title of each component describes the functionalities supported related to a specific concern required to provide the different NeoCam functionalities.

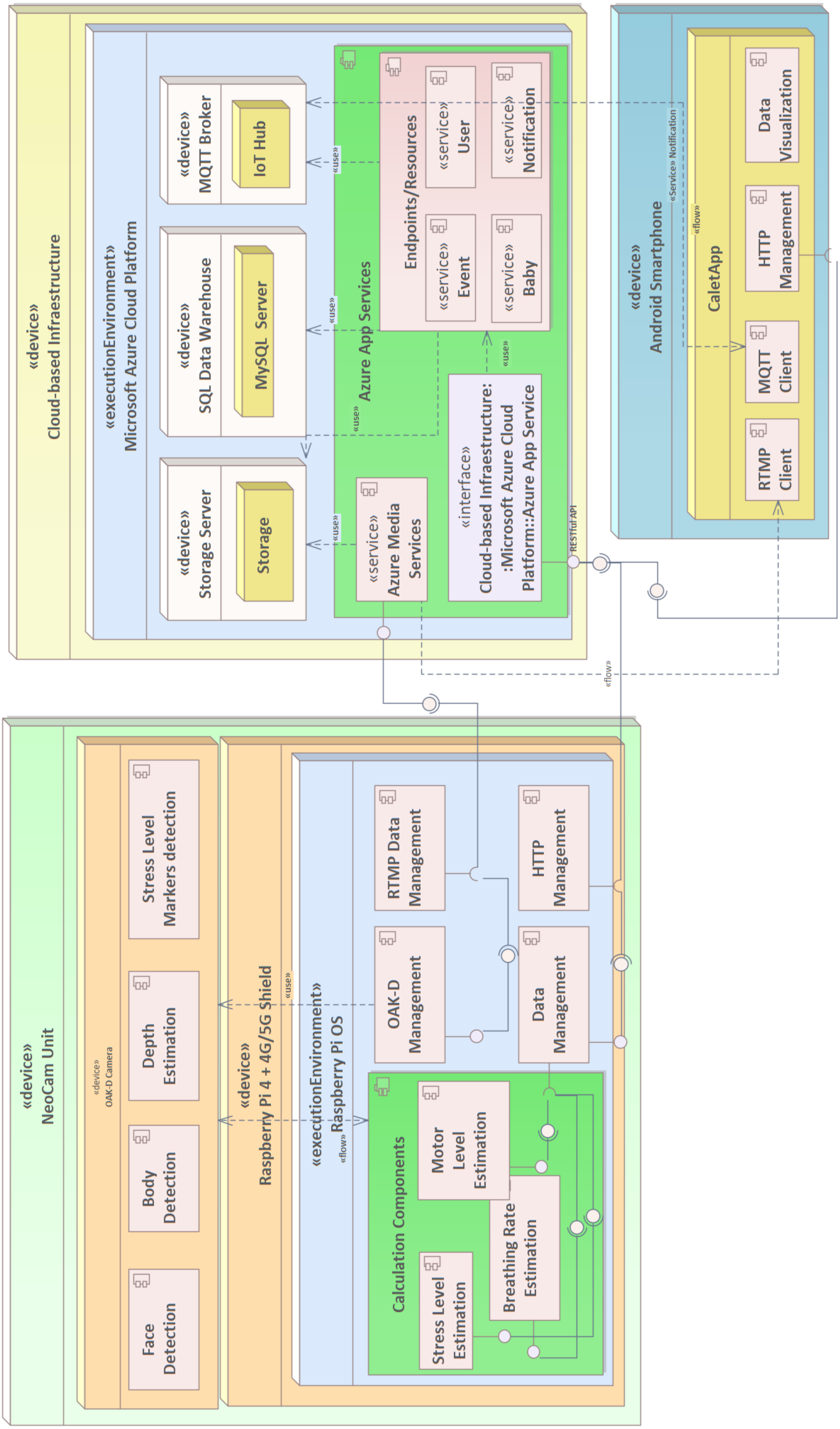


Figure 5: Development View of NeoCam

3 NeoCam Unit

This section expands the information given in Section 2 as part of the *Physical View* of the *4+1* view architectural model, by describing the hardware specifications of the NeoCam Unit.

The NeoCam Unit is the core element of the NeoCam platform, allowing the *1)* sensing of images, recording of information, *2)* application of conventional and AI-based algorithms (edge-computing oriented) and *3)* the exchange of information with the cloud through a hybrid access network (WiFi + Celullar Data).

The NeoCam Unit has been designed to be used in a real NICU with the goal of minimising its impact in the crowded environment of an incubator. Healthcare professionals must interact frequently with the infants, therefore monitoring solutions must be installed without affecting the normal care protocols. The NeoCam Unit is intended to be easy to install, compact, handy and with a common power supply for all internal components. Figure 6 shows the different hardware components that compose the NeoCam Unit, which we describe below.

Figure 6: Open 3D printed case and components included for the NeoCam Unit

Camera

As core element, the NeoCam Unit operates with an OAK-D camera from Luxonis. It has two monochrome and one RGB image sensors and integrates the Myriad X coprocessor, which is a Vision Processing Unit (VPU) from Intel®. The two stereo monochrome cameras allow precise depth perception for applications where it is necessary to measure distances, which is an essential component for the breathing rate measuring algorithm. These cameras have a resolution of 1280x800 pixels and a maximum frame rate of 120 fps. The RGB camera has a resolution of 12MP-4056x3040 pixels and a maximum frame rate of 60 fps. The VPU module with a computing capacity of 4 trillion Ops/sec was used to process the image frames with three deep learning ML models (CNNs) running in parallel at frame speeds of 25-30 fps.

Display

The NeoCam Unit includes a TFT 7" touch screen (800x400 pixels). It is used to check the video captured by the unit, to display data and curves and to select the size and location of the ROI used for breathing rate detection (box in yellow color in Figure 7 below).

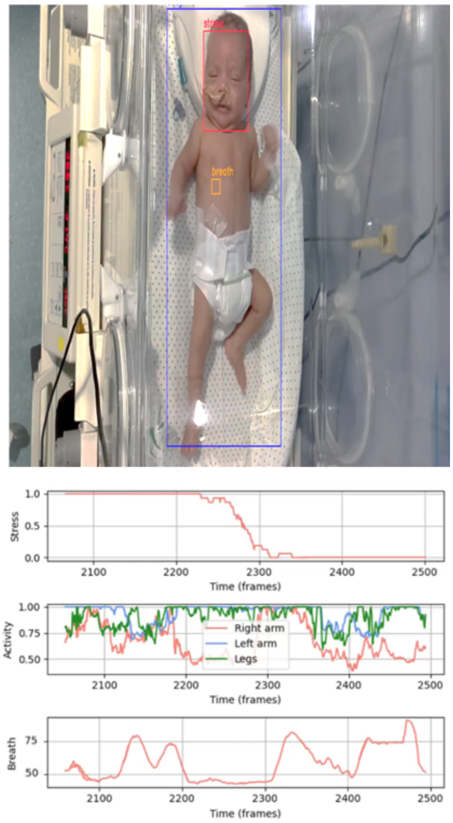


Figure 7: Region of Interest for breathing rate detection

Raspberry Pi

As CPU (Central Processing Unit) of the NeoCam Unit, this component allows the deployment of the software, the integration of the other components, part of the processing of the information and sending data to the cloud. The version used is Raspberry Pi 4 - 8GB RAM.

Connectivity Shield

Along with the WiFi®communication protocol supported natively by the Raspberry Pi 4, this shield extends the connectivity providing access to the cellular networking, enabling a hybrid access network for the NeoCam Unit.

SD Card

The SD Card, plugged in into the Raspberry Pi, just contains the operating system (Raspberry Pi OS), the required libraries to run the software and the software (see

NeoCam Unit Software repository in the Repository - Section 5-)

Hard Drive

A 2 TB (Terabyte) external HDD (Hard Drive Disk) is included in the design to store information (recorded video, measured times series form the infant). In case of a network failure, this will avoid information loss.

Plastic Case

Furthermore, we designed and fabricated an enclosure for the components using a 3D printer (Ref. Prusa i3 MK3S) and ABS plastic. Figure 8 shows different perspectives of the 3D model of the NeoCam case drawn using the CAD software `SolidWorks`, and Figure 9 illustrates the 3D printed case. The design of the box has the goal of including all the necessary components for the correct functioning of the system, minimizing its size. The full case contains different parts and specifications. On the bottom side a cylindrical support has been designed to hold the NeoCam Unit with clamps secured at the end of an articulated arm (Refs. Manfrotto 035 and 244N respectively). This allows the device to be placed above the incubator with the camera pointing towards the infant. The case also includes two slots, the peripheral slot is used to plug in or plug out components according to the user's needs, for example, a battery or a hard drive. The SD slot allows direct access to the computer's micro SD card (Raspberry Pi 4). The design also includes ventilation grills to help reducing the operating temperature inside the NeoCam Unit and a socket for plugging.

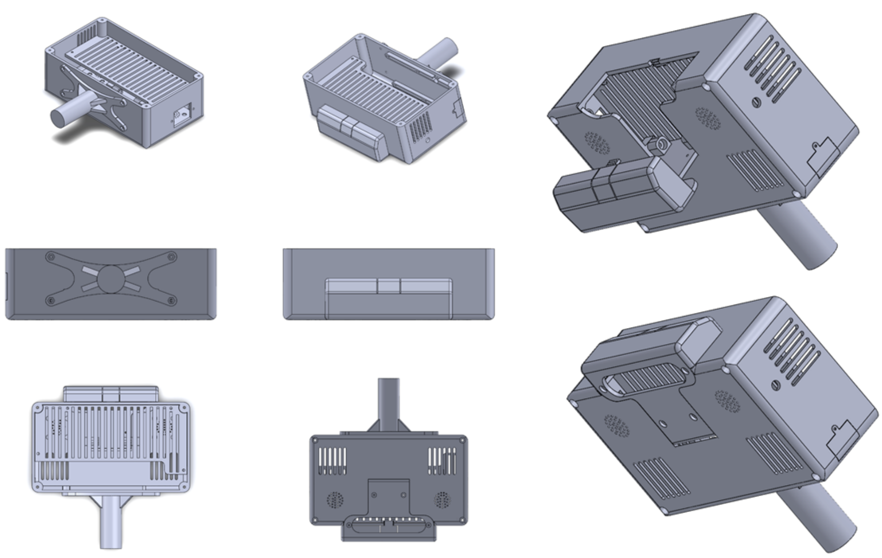


Figure 8: 3D model of the NeoCam unit

Moreover, the OAK-D camera is integrated in the case as a removable drawer that can be opened when the camera is in use with the advantage of exposing its heat-sink to the air (see Figure 10). This 90° opening allows the camera to be

Figure 9: 3D printed case and 3D design of the NeoCam unit

pointed directly at the infant while the screen is placed in a vertical position, so that it can be operated by healthcare professionals. The design includes circular grills for the possible incorporation of a microphone and loudspeaker. In this way, the system would have more possibilities to interact with the environment.

The NeoCam Unit includes an external plug for a power supply, model TXLN 060-105 of 5V@10A. The power is adjusted with a trimmer so that the voltage supplied to the Raspberry Pi does not go below 5.1V at operating conditions. It also allows powering the OAK-D camera and the touch screen display. OAK-D power consumption usually stays below the 900ma, but power of 1.5A or greater is recommended.

In short, the NeoCam Unit is a device that is versatile enough to change or expand its functionality depending on the user's needs. Its compact design allows it to be integrated into the crowded space of an incubator.

Figure 10: The NeoCam unit

4 Neocam Mobile App

As part of NeoCam platform we have developed a mobile application designed mostly for health professionals, but also adaptable to parental use. The application displays different information (views) depending on the type of user, enabling real-time monitoring, video streaming, and also reports based on processing historical data and real-time notifications.

The entire ecosystem of the application example (NeoCam platform) is depicted in Figure 11.

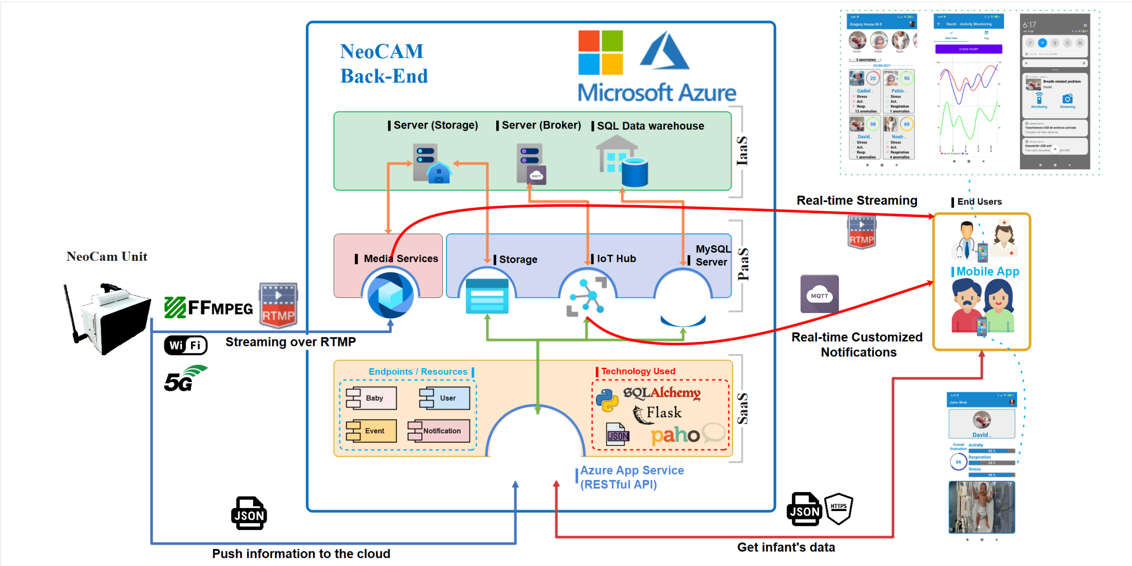


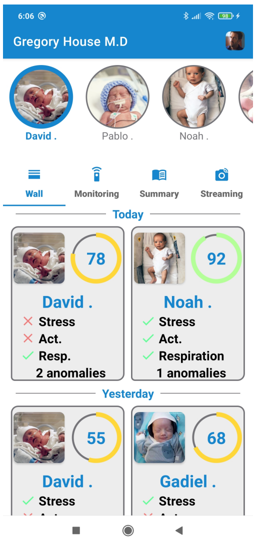
Figure 11: Application Example Ecosystem

The mobile app currently implemented in the NeoCam project is a beta version. The source code as well as the `apk` file can be found in the *Repository* (see Section 5). The main features of the mobile application are:

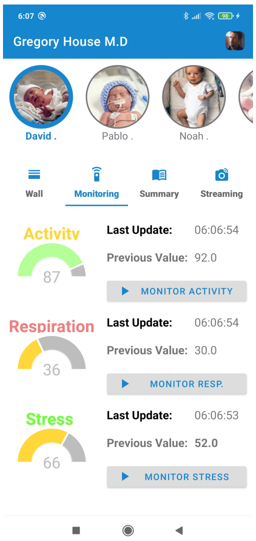
- Android-based mobile application for Android 4.4 KitKat or above, thus able to run in 94.1% of Android-based devices.
- Role-based views/frontend for health professionals and family members.
- Real-time notifications for alerts, information messages or other demanded features. This functionality has been implemented using the `Mqtt Paho` library provided by Eclipse Foundation [1].
- Real-time streaming over RTMP, implemented using `Exoplayer`[2], developed and supported by Google®.
- Historical data and real-time charting to display relevant variables. The charting has been implemented using the open-source `MPAndroidChart` library[3].

[1] https://www.eclipse.org/paho/index.php?page=clients/android/index.php
[2] https://exoplayer.dev/
[3] https://github.com/PhilJay/MPAndroidChart

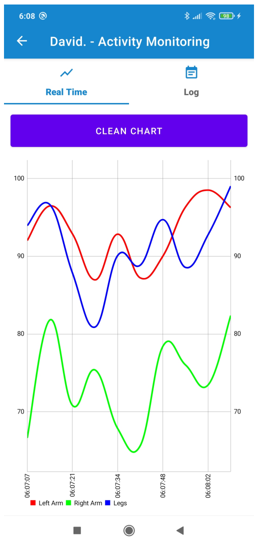
Some screenshots of the mobile app are depicted in Figure 12. With the aim to show the different functionalities supported and implemented in NeoCam platform provided, some of the data depicted in the screenshots is synthetic, such as the neonates profiles and the historical data for privacy reasons (GDPR - General Data Protection Regulation). A video demonstration of the mobile application can be found in the Repository (see Section 5).



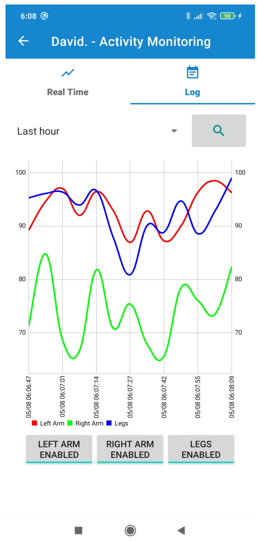
(a) Healthcare professional Wall



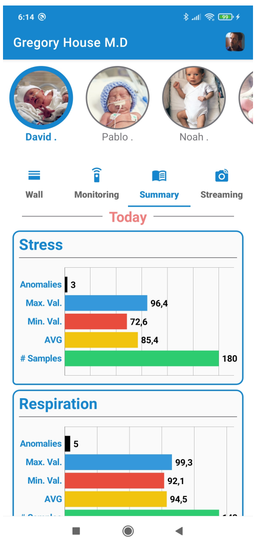
(b) Real-time monitoring



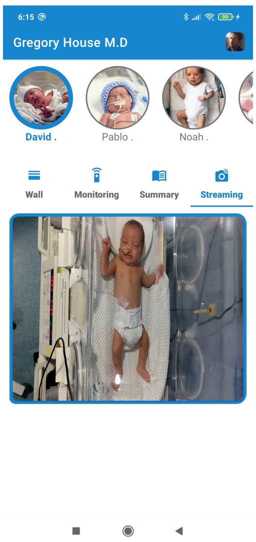
(c) Real-time charting



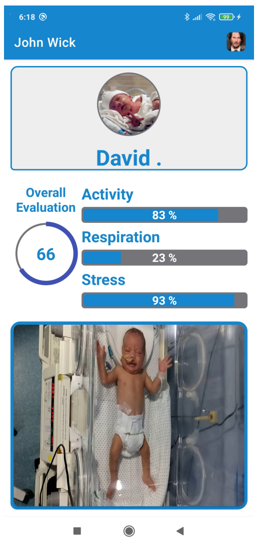
(d) Historical Data



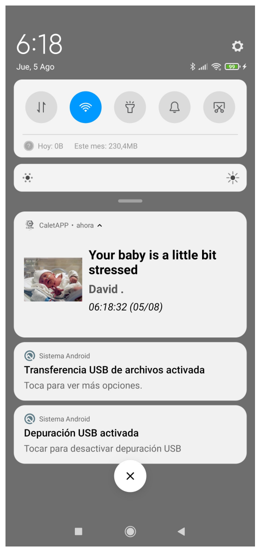
(e) Neonate Summary



(f) Real-time Streaming



(g) Relatives main view



(h) Pop-up notification

Figure 12: Mobile App Screenshots

5 Source code

In this section we provide links to all of the source repositories for the components of NeoCam.

Computer Vision and Machine Learning source code

Pose Estimation (Motor Level Activity)
https://github.com/Caleta-Team-UCA/neocam-pose

Stress Level Detection
https://github.com/Caleta-Team-UCA/Baby-Stress

Breathing Rate
https://github.com/Caleta-Team-UCA/neocam-breath

Cloud-based Back-end

https://github.com/caleta-team/Caleta-Backend

https://github.com/caleta-team/caleta-lib-backend

Mobile Application

https://github.com/Caleta-Team-UCA/Android-CaletAPP

NeoCam Unit Software

https://github.com/Caleta-Team-UCA/OAK_module

NeoCam Unit Design

https://github.com/Caleta-Team-UCA/NeoCamUnit-Design

6 Example videos

The demonstration videos of NeoCam are available online for the audience and can be found in the following links.

OpenCV AI Competition 2021 - Spot

https://youtu.be/ztfAAlU6diQ

OpenCV AI Competition 2021 - Teaser

https://www.youtube.com/watch?v=58KHGucW0dQ

Example of breathing rate measurement at the NICU

https://youtu.be/ZsHf2NaaHW8

Example of pose estimation with bounding box

https://youtu.be/CGLl9O9GtEg

Stress detection with MobileNet model

https://youtu.be/hLJMXC_qkGE

Example of parallel operation of the three algorithms

https://youtu.be/8-UzwSKodH0

Mobile Application example of use

https://youtu.be/RZ0ePH552yk