

Revue

Mattia Matteini

mattia.matteini@studio.unibo.it

Alberto Paganelli

alberto.paganelli3@studio.unibo.it

March 2023

Revue is a real-time video surveillance and environment monitoring system. It is designed to be used in multiple scenarios such as home, office or warehouses following the user needs. Composed by multiple features, it permits high modularity, allowing a more complex usage through the video streaming detection of a predefined set of object classes or simply to monitoring camera streams.

1 Requirements

The goal of the project is to develop a distributed software system which is able to monitor the environment of a certain area through sensors and cameras, providing real-time data and video streaming.

Moreover, to enhance the usefulness of the system, it should also be able to notify the user when specific conditions are met. These conditions include detecting if sensor data exceeds a predetermined range or if some camera recognizes a particular object. This notification feature ensures that the user is promptly informed about critical events or anomalies in the monitored environment.

The outcome should be a reliable system adaptable to different scenarios, such as smart cities, industrial, or simply home monitoring.

In the following are listed the main requirements of the system.

1.1 User Requirements

1. The user can authenticate to the system through a web interface.
2. The user can monitor the environment data produced by the sensors.
3. The user can monitor the video stream produced by the cameras.

4. The user can add/delete a device to the system.
5. The user can enable and disable a device.
6. The user can modify a device configuration.
7. The user can add/delete a security rule regarding a camera/sensor.
8. The user can modify a security rule.
9. The user can delete received notifications.
10. The user can consult the history of produced data.

1.2 System Requirements

1. The system grants access only to authenticated users.
2. The system provides a web interface as an entry point for the user.
3. The system generates video and data streams.
4. The system monitors streams to detect anomalies.
5. The system notifies the user when a security rule is violated.
6. The system persistently stores produced data.

1.3 Non-functional Requirements

1. The system should be modular and reliable. In particular:
 - a) The system should work even though the recognition component is down or not deployed.
 - b) The system should work even though the component responsible for the storage of the data is down or not deployed.
 - c) The system should work even though the component responsible for the authentication is down.
2. The system should be as much as possible available (and also replicable).
3. The system should be usable, with a user-friendly and minimal interface.

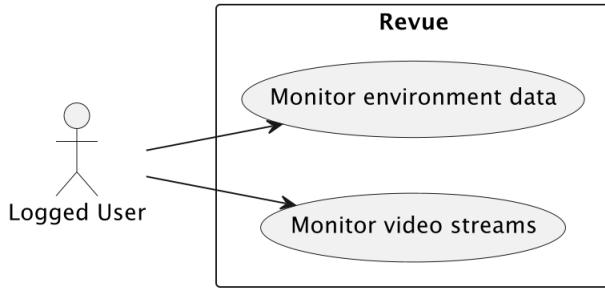


Figure 1: Simple Use Case

1.4 Implementation Requirements

1. The recognition component of the system should be implemented in Python.
2. The frontend of the system should be implemented using Vue 3 and Typescript.
3. The storage of data should be implemented using a NoSQL database.
4. The system should be implemented using a microservices' architecture.
5. The system should be deployed using Docker.

1.5 Scenarios

The system can be used in various scenarios, depending on the user needs. This system is designed to be used by multiple types of users, from a private user to a company director.

In the sections below, we will describe two main possible scenarios in which the system can be used.

In the simplest scenario, the system is used by a private user, who wants just to monitor his home or a particular environment without the necessity to recognize the objects in the video. In this case, the user can just rely on the camera, monitoring the home or a proprietary field. The user is free to monitor the live video by the camera whenever and wherever he/she wants, using the browser on the smartphone. The user can also set up sensors to monitor data from the environment.

A more complex scenario could involve both sensor and camera usages with the support of a neural network to detect intrusion. For example, the director of food wholesale could monitor the temperature of the warehouse and the presence of unauthorized people during the night. In this case, the recognition part of the system is necessary to detect whenever an intrusion occurs.

Moreover, supply chain monitoring can be done for who's needs to ensure that the temperature of the warehouse is always in the right range and be alerted whenever the temperature exceeds a certain range to detect or prevent problems.

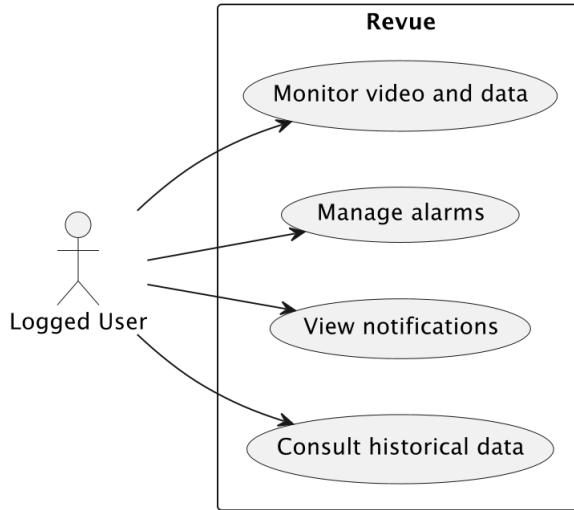


Figure 2: Advanced Use Case

1.6 Self-assessment policy

The project can be considered completed when **all** requirements are satisfied.

In particular, non-functional requirements aim to grant a good general quality of the system. This will be achieved also using automated tests that will ensure, among other things, the quality of code production.

2 Requirements Analysis

Drawing up requirements, one relevant considered topic is the recognition feature. This is supposed to be developed using Python and exploiting its main libraries for video processing and object recognition, to minimize the abstraction gap.

Another important aspect is the handling of video streams. In fact, to facilitate the development, an implicit requirement is necessary: the use of an ad hoc *media server*. This permits also improving the compatibility permitting to produce and consume using different protocols.

Eventually, internal communications between devices and services need to be guaranteed. This implicitly leads to the use of a message broker (*Kafka*) which guarantees better scalability and at least one message delivery policy.

3 Design

3.1 Ubiquitous Language

For the initial design phase, it's useful to define a common language that permits referring to the concepts with coherence and no ambiguity. This is a fundamental part of Domain

Term	Meaning
Camera	Device that records an environment and sends the data to the central system
Sensor	Device capturing sensing data from an environment (e.g. temperature)
Device	Either a camera or a sensor
Video Stream	Stream of video data produced by a camera
Environment Data	Data produced by a sensor
User	User that can access the system
Detection	Recognition of an object in a video stream
Intrusion	Detection of an unauthorized object
Exceeding	Environment value exceeding user defined ranges
Anomaly	Either an intrusion or an exceeding
Security Rule	Rule defined by the supervisor to trigger anomalies
Notification	An alert sent to the user to inform that an anomaly has been triggered.

Table 1: Ubiquitous Language

Driven Design philosophy.

In table 1 is shown the designed ubiquitous language, while in table 2 are reported the synonyms.

3.2 Architecture

The overall system is designed with microservices architecture. This choice helped us to increase modularity, scalability, reliability and fault tolerance. The system is composed of the following microservices:

- **Authentication Service:** responsible for the authentication and access control.
- **Monitoring Service:** responsible for managing devices and environment data.

Term	Synonyms
Camera	Video camera
Video Stream	Video, Transmission
Environment Data	Data, Sensing Data
User	Supervisor, Admin
Security Rule	Rule

Table 2: Synonyms

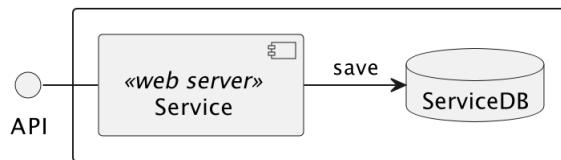


Figure 3: Microservice components

- **Recognition Service:** responsible for the recognition of objects in the video streams.
- **Alarm Service:** responsible for the management of the security rules and anomalies.
- **Notification Service:** responsible for sending notifications to the user.
- **Log Service:** responsible for the persistent saving of data.

Each microservice consists of 1. Web server exposing REST APIs 2. Database to store its data (except for the **Recognition Service**) (figure 3).

Moreover, other components are necessary to make the system work:

- **Frontend:** provides to the user the web interface to interact with the system.
- **Sensors:** capture the environment data and send them to the rest of the system.
- **Cameras:** capture the video streams and send them to the rest of the system.
- **Media Server:** used to consume the produced video streams and make them available using different protocols.
- **Broker:** used to manage some internal communications.

In figure 4 is presented the whole architecture diagram.

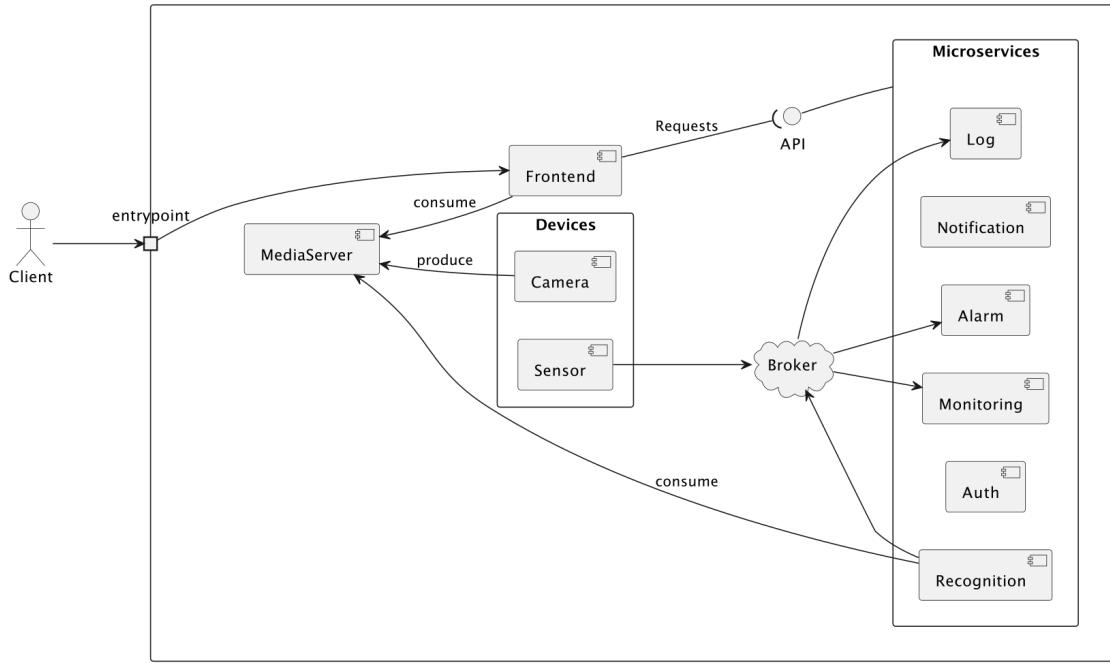


Figure 4: Revue Architecture

3.3 Structure

For the design phase, Domain Driven Design (DDD) and Hexagonal Architecture (HA) have been adopted. Actually, the adherence to DDD and HA can be considered a little bit rough (for example, because of the lack of an ad hoc presentation layer) and it will be improved in the future.

To briefly specify the layers' dependencies:

- **Domain** layer cannot depend on any other layer.
- **Application** layer (which contains business logic) can depend only on Domain layer.
- **Storage** layer depends on the layers above. It is the outer layer since it contains platform-dependent implementation.

Each microservice has the same structure in terms of classes and packages. Furthermore, it is responsible for a specific subset of domain entities.

In figure 5, is represented the general packages/classes structure.

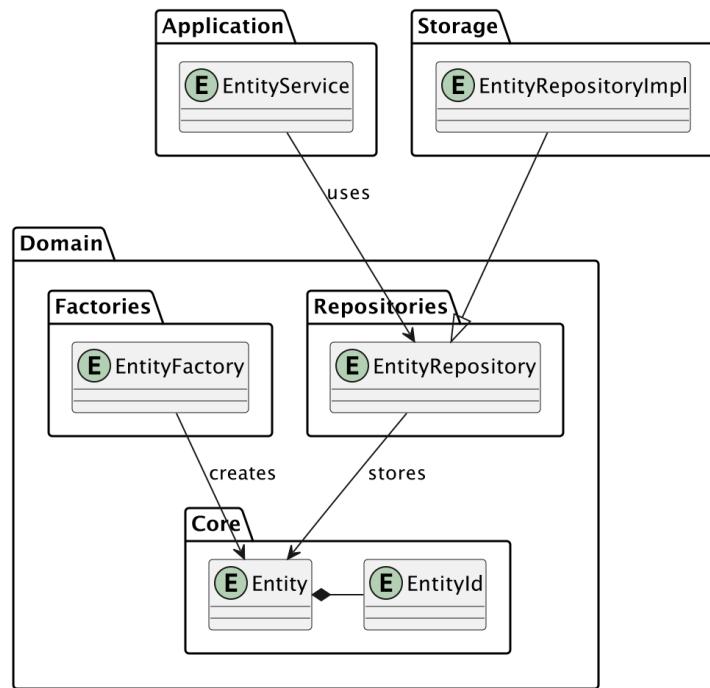


Figure 5: General structure of microservice

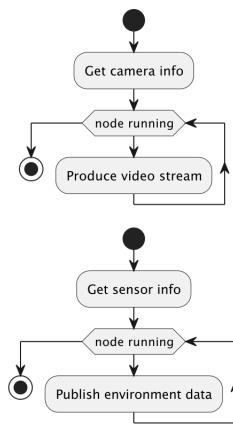


Figure 6: Device activity diagram

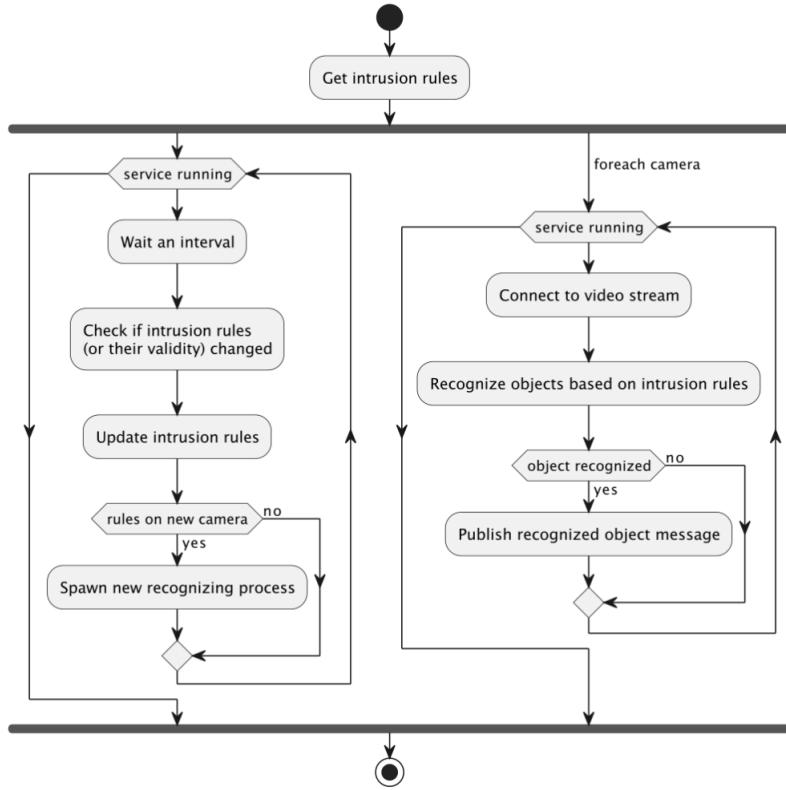


Figure 7: Recognition service activity diagram

3.4 Behaviour

3.4.1 Monitoring Service

Microservice relative to the monitoring of the environment data retrieved from sensors or active streams retrieved from cameras. It allows also adding, delete or modify a device configuration, and it is responsible for the management of the devices.

3.4.2 Recognition Service

Microservice in charge of object recognition on the camera streams. The service is able to recognize a set of predefined objects and notify the Alarm Service, that is in charge of the alarm management. For every camera stream, a topic and a recognition process is created and started. When a predefined object is recognized it is sent through the relative topic.

3.4.3 Alarm Service

Microservice responsible for the alarm management. It is able to check the data coming from the sensors or the recognized objects on cameras' streams. The service needs only

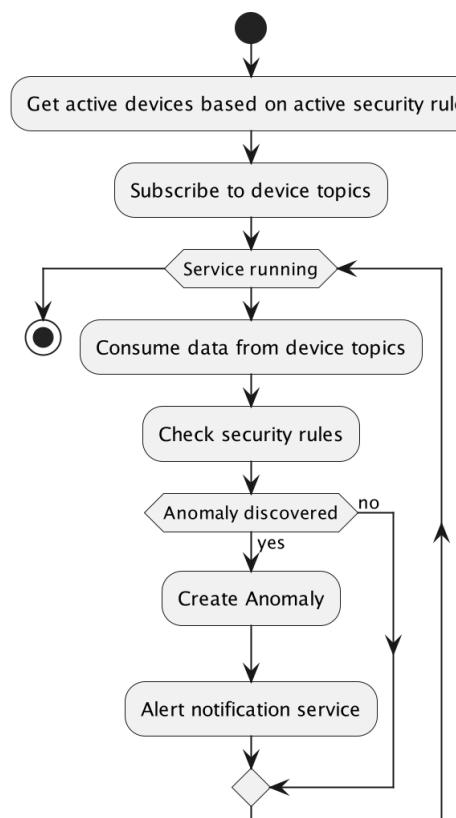


Figure 8: Alarm service activity diagram

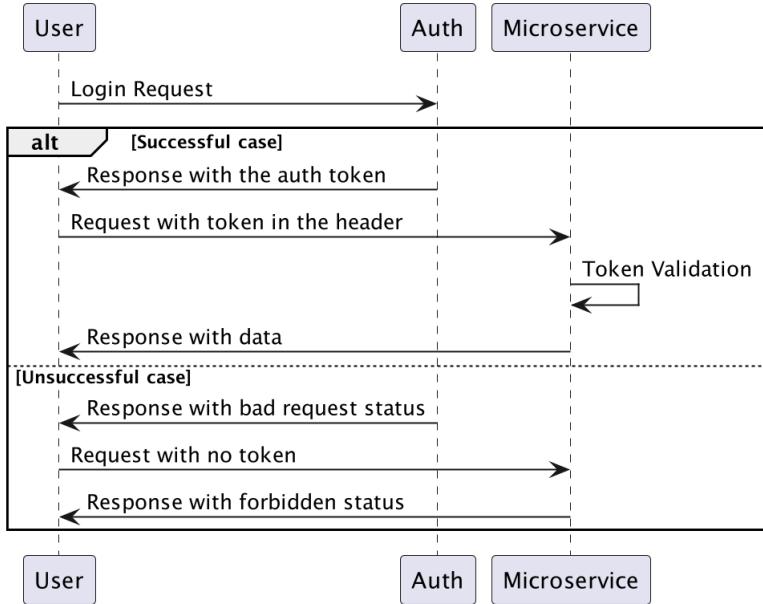


Figure 9: Auth service sequence diagram

to check active rules for active devices. It is able to create an anomaly, store it and to notify the notification service if the data is not compliant with the rules. Moreover, this service is in charge of the management of the security rules, allowing the user to modify their configuration.

3.4.4 Notification Service

This microservice is responsible to notify the user in case of Anomaly and store them. When the Alarm service detects an Intrusion or an Exceeding, it sends a message to the Notification Service that will notify the user. Moreover, the notification is in real-time if the user is logged in.

3.4.5 Log Service

Microservice responsible for the storage of the environment data retrieved from the sensors. Moreover, it allows the user to consult the historical data of the environment retrieving them when requested from the persistence.

3.5 Interaction

3.5.1 Auth Service

The Auth Service is responsible for the authentication of the users. When a Login request is performed, the Auth Service checks the credentials and returns a token if the user is authenticated. When the user wants to perform a request to another service,

the user needs only to provide the token in the header of the request. Every service contains a validation middleware where the token is checked. This process has been implemented through the use of JSON Web Token and sharing the secret key between federated services.

How should entities interact with each other? (UML Sequence Diagram)

4 Implementation Details

4.1 Kafka

Apache Kafka is the technology chosen to handle intra-system real-time communications.

In particular, KafkaJS and kafka-python clients have been used respectively for the Node.js and Flask services.

Kafka is ...

In the following, is reported the code for producing (Listing 1) and consuming (Listing 2) messages using KafkaJS.

Listing 1: Producing using KafkaJS

```

1 const kafka: Kafka = new Kafka({
2   clientId: 'SENSOR_${SENSOR_CODE}',
3   brokers: ['${kafkaHost}:${kafkaPort}']
4 })
5
6 export const produce = async (): Promise<void> => {
7   const producer: Producer = kafka.producer({ createPartitioner:
8     Partitioners.LegacyPartitioner })
9   await producer.connect()
10  setInterval(async (): Promise<void> => {
11    await producer.send({
12      topic: 'SENSOR_${sourceSensor.deviceId.code}',
13      messages: [
14        {
15          value: JSON.stringify(values)
16        }
17      ]
18    }, sourceSensor.intervalMillis)
19  })
}
```

Listing 2: Consuming using KafkaJS

```

1 const consumer: Consumer = kafkaManager.createConsumer('alarmConsumer')
2
3 export const setupConsumer = async (): Promise<void> => {
4   await consumer.connect()
5   await consumer.subscribe({ topics: await getTopics(), fromBeginning:
6     false })
7   consumer
8     .run({
```

```

8     eachMessage: async ({ topic, message }): Promise<void> => {
9         // message arrived!
10    }
11  })
12  .then(() => console.log('Consumer running'))
13 }

```

4.2 Sockets

Socket IO is a library that enables real-time, bidirectional and event-based communication between the browser and the server. It has been exploited to implement the real-time communication between the user and the system, in particular for pushing notifications or sending the environment data to the user. A security layer has been added to socket servers to ensure secure connections. Also for this feature, the JWT token generated when the user logs in has been used.

Listing 3: Socket Server middleware

```

1 io.use(function (socket, next): void {
2     if (socket.handshake.query && socket.handshake.query.token) {
3         if (jwtManager.verify(socket.handshake.query.token as string)) next
4             ()
5     } else {
6         next(new Error('Authentication error'))
7     }
})

```

4.3 Object Recognition with YOLO

You only look once (YOLO) is a state-of-the-art, efficient real-time object detection algorithm. YOLO is able to recognize classes of objects and its position in the video.

This algorithm is used within the **Recognition** service to perform object recognition on video stream produced by the cameras, according to active security rules.

In Listing 4 is reported the responsible code for this task.

Listing 4: Python class performing object recognition with YOLO

```

1 class Recognizer:
2
3     def __init__(self, camera_code: str, rtsp_stream_url: str):
4         yolo_resource: str = "app/resources/yolov3"
5         with open(f"{yolo_resource}/coco.names", "r") as f:
6             self.classes: [str] = [line.strip() for line in f.readlines()]
7
8         self._camera_code: str = camera_code
9         self._rtsp_stream_url: str = rtsp_stream_url
10        self._is_recognizing: bool = False
11        self._recognized_objects: [str] = []
12        self._net = cv.dnn_DetectionModel(

```

```

12         f"{yolo_resource}/yolov3.weights", f"{yolo_resource}/yolov3.
13             cfg"
14     )
15
16     def start_recognizing(self) -> None:
17         os.environ["OPENCV_FFMPEG_CAPTURE_OPTIONS"] = "rtsp_transport/tcp
18             "
19
20         # load capture
21         capture = cv.VideoCapture(self._rtsp_stream_url, cv.CAP_FFMPEG)
22         capture.set(cv.CAP_PROP_FRAME_WIDTH, 640)
23         capture.set(cv.CAP_PROP_FRAME_HEIGHT, 480)
24
25         self._is_recognizing = True
26         while self._is_recognizing:
27             ret, frame = capture.read()
28             if not ret:
29                 break
30
31             # Detecting objects
32             class_ids, confidences, _ = self._net.detect(frame,
33                 confThreshold=0.5)
34
35             # ... process the detected objects and publish to Kafka
36
37             capture.release()
38
39     def stop_recognizing(self) -> None:
40         self._is_recognizing = False
41
42     def is_recognizing(self) -> bool:
43         return self._is_recognizing

```

4.4 Media Server

MediaMTX has been used to allow the system to support more than one protocol without implementing a single procedure for each of them. All the cameras are linked to the media server, and it can be used to retrieve the streams from the cameras with a single protocol. In this case the RTSP protocol has been exploited.

4.5 WebRTC

To simulate the camera streams, the WebRTC protocol takes place. It has been selected for its ability to stream video and audio in real-time with simplicity. It does not require any plugin or software installation, it is supported by all the major browsers, and it is open-source. Developed by Google, it implements the google congestion control (GCC) algorithm that allows to stream video and audio in real-time with a low latency.

4.6 Single Sign-On

The Single Sign-On (SSO) has been implemented to allow the user to access the system with a single set of credentials. The Auth Service is responsible for the authentication of the user and the generation of the JWT token that will be used to authenticate the user in the other services. The generated token can be validated from each microservice to ensure that the user is authenticated. Following this approach, in case of failure of the authentication service, the user can still access the system until its token validity expires. Moreover, the single point of failure is avoided. This process has been implemented through the use of JSON Web Token and sharing the secret key between federated services.

Listing 5: Middleware for the microservices

```
1  authenticate(req: Request, res: Response, next: NextFunction) {
2    const authHeader = req.headers['authorization']
3    const token = authHeader && authHeader.split(' ') [1]
4    if (token == null) return res.status(HttpStatusCode.FORBIDDEN)
5
6    console.log('Authentication token: ' + token)
7    this.jwt.verify(token, this.secret, (err: any, _user: any) => {
8      if (err) return res.sendStatus(HttpStatusCode.UNAUTHORIZED)
9      next()
10     })
11   }
```

5 Self-assessment / Validation

5.1 Quality Assurance

Two main tools have been used to ensure the quality of the code produced:

- Prettier is a code formatter that supports many languages. It enforces a consistent style by parsing code and re-printing it according to the configuration rules.
- ESLint Is a tool that statically analyses code to find suboptimal patterns and errors.

Both tools have been integrated into the Continuous Integration pipeline (section 5.5) to keep the high-quality code production.

5.2 Architectural Testing

In order to ensure that layers' dependencies are respected, Dependency Cruiserframework has been exploited.

Essentially, the configured rules check that:

- **Domain** layer does not access to any other layer.

- **Application** layer can access only the Domain layer.
- **Presentation** layer can access only Domain and Application layers.

5.3 API Testing

API testing has been performed using Vitest framework.

To be able to execute the tests, the database has been mocked using MongoDB Memory Server.

In Listing 6 is reported a simplified example of an API test.

Listing 6: API testing example

```

1  describe('GET /devices/', () : void => {
2    beforeAll(async () : Promise<void> => {
3      await connectToMock()
4      await populateDevices()
5    })
6
7    describe('GET /devices/sensors', () : void => {
8      it('responds with a forbidden status if no auth token is provided', {
9        async () : Promise<void> => {
10          const sensors: Response = await monitoringService.get('/devices/
11            sensors')
12          expect(sensors.status).toBe(HttpStatusCode.FORBIDDEN)
13        }
14      })
15
16      it('responds with the sensors otherwise', async () : Promise<void> =>
17        {
18          const sensors: Response = await monitoringService
19            .get('/devices/sensors/')
20            .set('Authorization', `Bearer ${TOKEN}`)
21          expect(sensors.status).toBe(HttpStatusCode.OK)
22          expect(sensors.type).toBe('application/json')
23        }
24      })
25    })
26
27    afterAll(async () : Promise<void> => {
28      await disconnectFromMock()
29    })
30  })

```

5.4 Fault Tolerance Testing

Since reliability is an important non-functional requirement (requirement 1.3.1), a specific script has been set up to test the system behavior in case of faults.

In Listing 7 is reported the main part of the script used to 1. Tearing up the system
2. Tearing down some running services 3. Executing fault tolerance tests.

Nevertheless, script and tests could be improved by adding new different fault scenarios.

Listing 7: API testing example

```
1 echo "Tearing up the system..."  
2 ./deploy.sh > /dev/null 2>&1  
3 sleep 2  
4  
5 tear_down_services "log"  
6 execute_test "monitoring" "log"  
7  
8 tear_down_services "auth"  
9 execute_test "notification" "auth"  
10  
11 tear_down_services "notification"  
12 execute_test "alarm" "notification"  
13  
14 tear_down_services "sensor-1" "sensor-2"  
15 execute_test "monitoring" "sensor"  
16  
17 tear_down_system 0
```

5.5 Continuous Integration

Each test previously described in this section has been integrated into the Continuous Integration pipeline.

6 Deployment

To deploy the system, the Docker daemon has to be running on the machine.

The system is decomposed in a container for each service and a container for the relative database3. In addition to these containers, other containers are used to deploy Kafka, Zookeeper, the Media Server and Recognition. To simulate running devices, two containers for each device are deployed.

Multiple scripts are available to start the system with some differences, to deploy only databases, a single service or the entire system.

For the development phase, a script running only services' database and Kafka has been exploited, and it's available. This script is called “compose-db.sh” and allows the user to deploy or undeploy databases based on the user inserted parameters.

Also, a script to deploy a single service and its database is available. It is called “compose-service.sh” and permits to operate always considering the service and the database like a single entity.

Moreover, for the entire system, the “deploy.sh” script has to be launched. This script will build the images and start the containers for each component.

Every script has to be launched from the root of the project.

6.1 Deployment Instructions

Clone Revue and navigate to the project root.

Service name	Service Port	Database Port
frontend	8080	—
auth	4000	27017
monitoring	4001	27018
alarm	4002	27019
log	4003	27020
notification	4004	27021
recognition	4005	—
media-server	8554 rtsp	—
kafka	9092	—
zookeper	2181	—

Table 3: Services binding ports

An .env file is present in the project root. Without modifying the .env file, the services will be exposed on different ports according to the table3.

To deploy the entire system, run the following command:

```
./deploy.sh
```

Keep in mind that an example user is already present in the database with the following credentials:

- Username: **user**
- Password: **user**

If instead of deploying the entire system, you want to deploy only specific services or a databases, you can use the other scripts. To deploy services, you have to use the “compose-service.sh” script while to deploy a database, you have to use the “compose-db.sh” script.

For these scripts, you have to specify some parameters. The first one is the “–up” or “–down” instruction to deploy or undeploy what you need. Following the instruction, at least one service name is required. Depending on the script you are using, the system will deploy or undeploy services and databases. Usage examples:

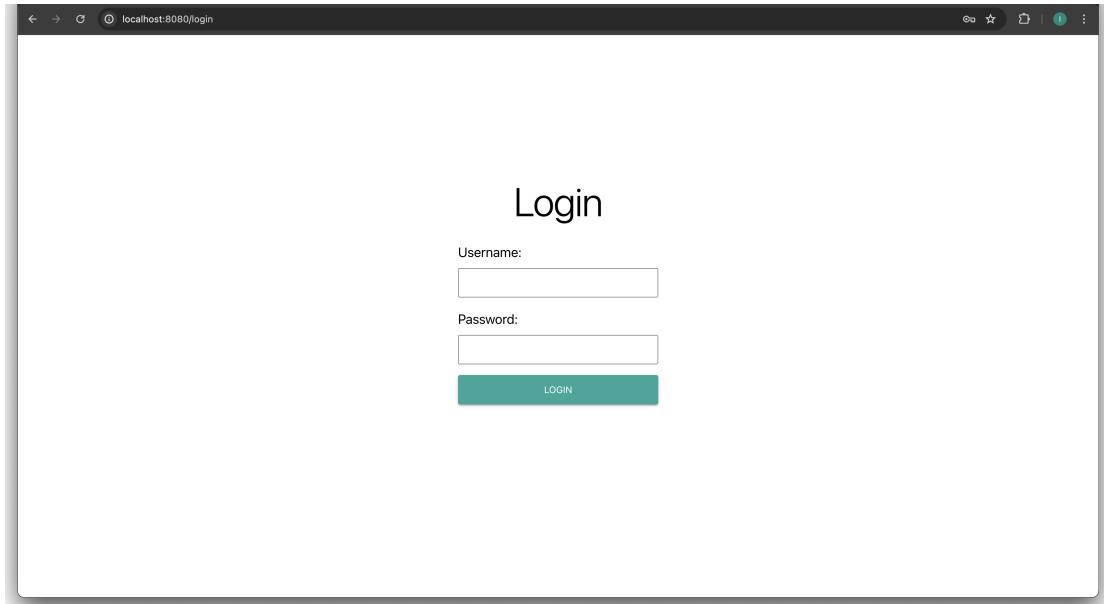


Figure 10: Login view

```
./compose-service.sh --up monitoring alarm auth notification  
./compose-db.sh --up monitoring alarm auth notification
```

NB: Scripts have to be launched from the root of the project.

7 Usage Examples

For every usage, the system requires a login for security reasons.

In the simplest scenario, the user can see the section designated for sensor environment data or the camera video streams consultation.

In the more complex scenario, the user can add security rules to detect exceeding values or unauthorized objects in the video streams. When adding a new security rule, the user can choose the object class to detect or the threshold value (for a particular measure) in addition to the device and time slot in which the rule is active.

Both usages of the system consent to the user to add, delete or modify a device or a security rule configuration.

Moreover, the user can consult the history of produced data or all the notifications received by the system.

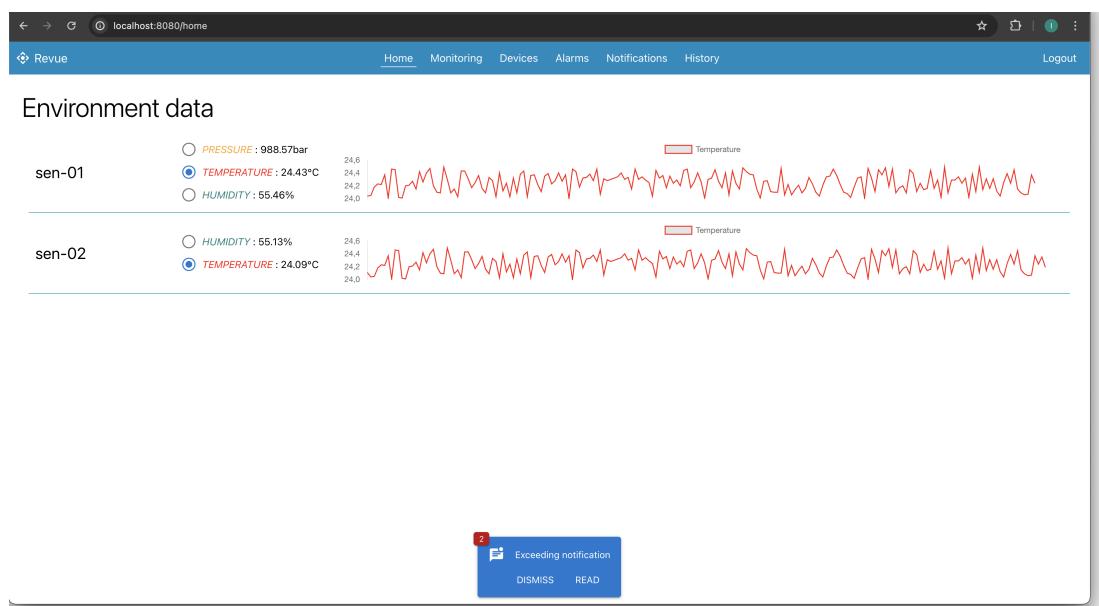


Figure 11: Home view

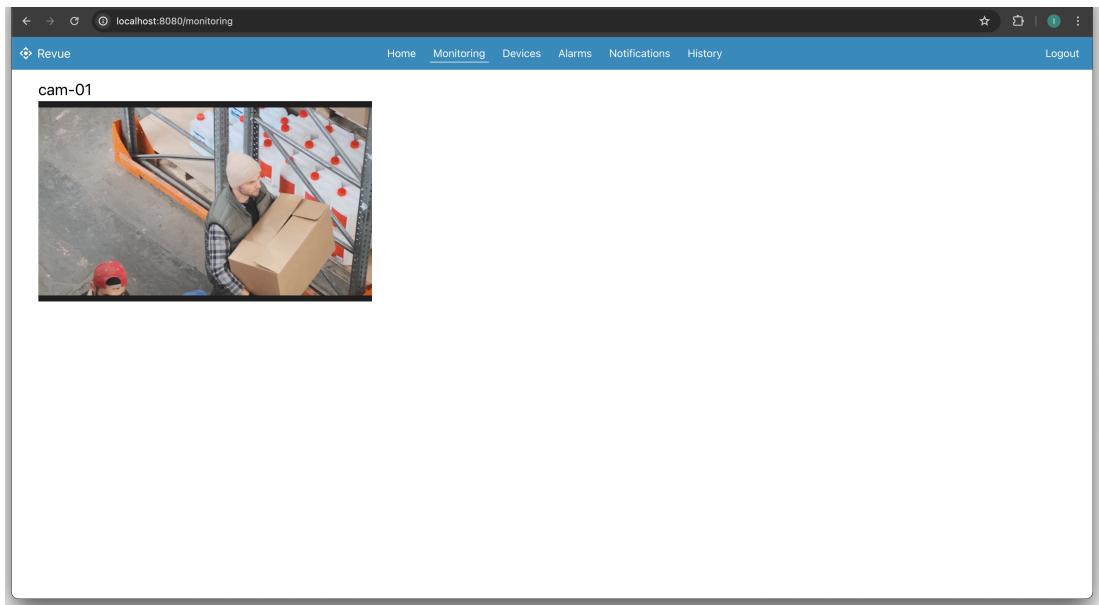


Figure 12: Monitoring view

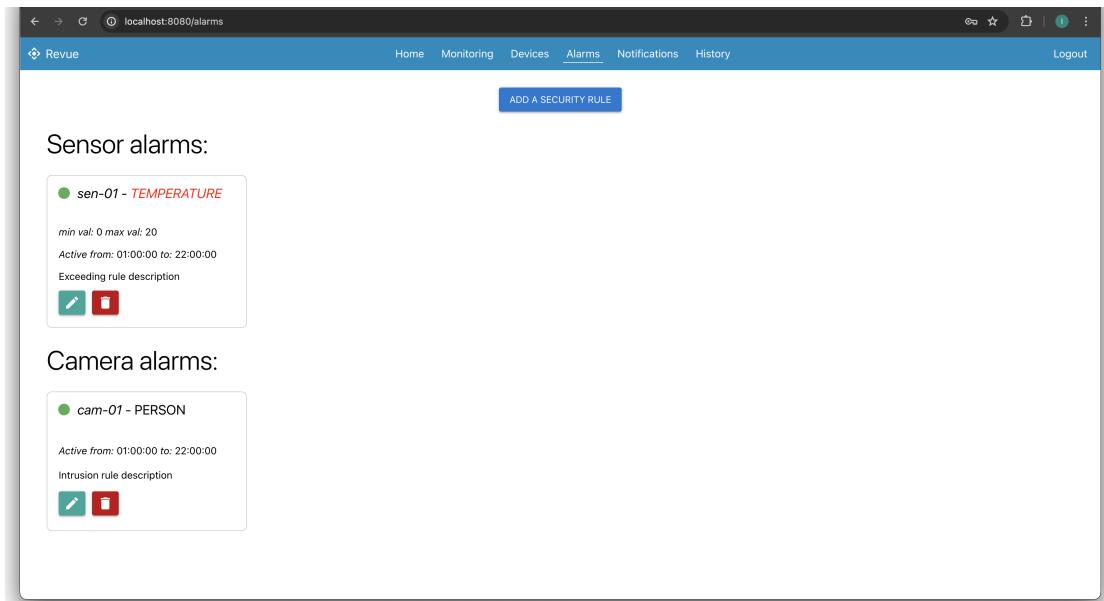


Figure 13: Security rule view

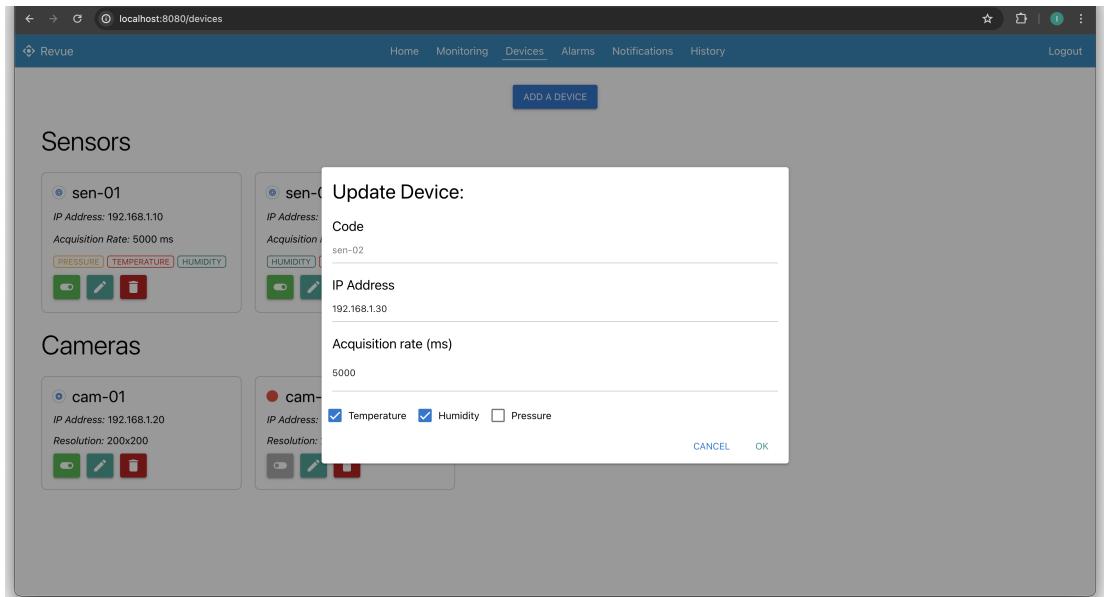


Figure 14: Updating a device

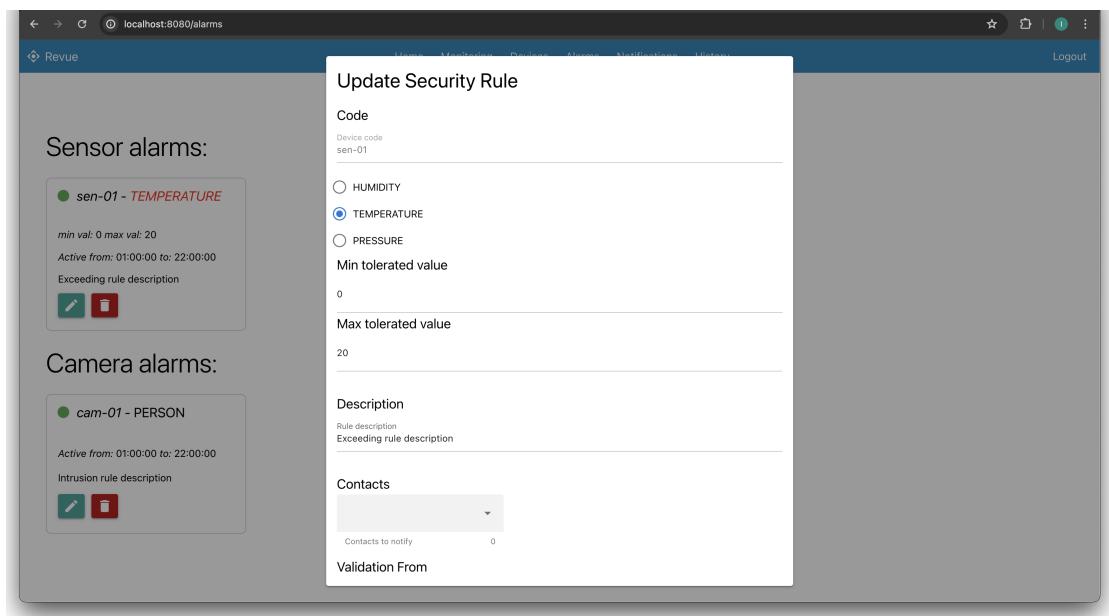


Figure 15: Updating a security rule

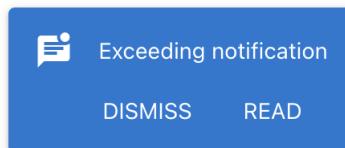


Figure 16: Notification alert

The screenshot shows a web browser window with the URL `localhost:8080/notifications`. The page has a header with tabs: Home, Monitoring, Devices, Alarms, Notifications (which is underlined), and History. A Logout link is also present. The main content area is titled "Notifications" and displays a list of 15 notifications. Each notification is enclosed in a blue-bordered box and contains the following information:

Icon	Device ID	Date	Message	Detection hour
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.34	09:50:13
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.11	09:50:08
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.08	09:50:03
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24	09:49:58
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.07	09:49:53
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.19	09:49:48
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.27	09:49:43
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.1	09:49:38
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.06	09:49:33
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.27	09:49:28
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.25	09:49:23
⚡	sen-01	16/5/2024	For the TEMPERATURE measurement a value out of range was detected. Value: 24.43	09:49:18

Figure 17: Security rule view

The screenshot shows a web browser window with the URL `localhost:8080/history`. The page has a header with tabs: Home, Monitoring, Devices, Alarms, Notifications, and History (which is underlined). A Logout link is also present. The main content area is titled "History" and displays a list of 15 history entries. Each entry is enclosed in a blue-bordered box and contains the following information:

Icon	Device ID	Date	Measurement	Value	Detection hour
⌚	sen-01	16/5/2024	PRESSURE	Measurement value: 997.06 BAR	09:50:18
⌚	sen-01	16/5/2024	HUMIDITY	Measurement value: 55.49 PERCENTAGE	09:50:18
⌚	sen-01	16/5/2024	TEMPERATURE	Measurement value: 24.04 CELSIUS	09:50:18
⌚	sen-01	16/5/2024	HUMIDITY	Measurement value: 55.14 PERCENTAGE	09:50:13
⌚	sen-01	16/5/2024	TEMPERATURE	Measurement value: 24.34 CELSIUS	09:50:13
⌚	sen-01	16/5/2024	PRESSURE	Measurement value: 981.48 BAR	09:50:13
⌚	sen-01	16/5/2024	HUMIDITY	Measurement value: 55.24 PERCENTAGE	09:50:08
⌚	sen-01	16/5/2024	TEMPERATURE	Measurement value: 24.11 CELSIUS	09:50:08
⌚	sen-01	16/5/2024	PRESSURE	Measurement value: 980.92 BAR	09:50:08
⌚	sen-01	16/5/2024	HUMIDITY	Measurement value: 55.09 PERCENTAGE	09:50:03
⌚	sen-01	16/5/2024	PRESSURE	Measurement value: 991.06 BAR	09:50:03
⌚	sen-01	16/5/2024	TEMPERATURE	Measurement value: 24.08 CELSIUS	09:50:03

Figure 18: Security rule view

8 Conclusions

8.1 Future Works

Future developments of this system will certainly have to enrich the user experience to exploit all the possible features offered by the system. Certainly a well-designed user section and the introduction of roles could open up to better configurability.

Real-time video consultation could be improved with the introduction of video recording functions as well as a recorded history, which has been put aside for now due to time restrictions.

Furthermore, Web of Things perspective is the objective for next courses' exams. This will lead to the refactor of existent API, the addition of Thing Descriptions, etc. Also, an upgrade to the RESTful API could be considered to make them HATEOAS compliant.

Another point that could certainly be worked on would be a refinement of the system design to make it even more scalable and maintainable. In particular, device management, which is currently part of the monitoring service, surely will be improved with the introduction of a dedicated service.

For the deployment of the system, the use of Kubernetes (k3s) will be considered to manage the containers in a more efficient way. The goal is to deploy the system in a Raspberry PI cluster.

8.2 What did we learned

This project allowed us to deepen our knowledge of the microservices architecture and to understand the advantages and disadvantages of this approach.

Moreover, it helped us to experiment with new technologies such as Kafka and a more in-depth testing.

Fault tolerance testing has been particularly interesting and has allowed us to understand how to manage the system in case of failure of one or more services, validating the reliability of the system.

Stylistic Notes

Use a uniform style, especially when writing formal stuff: X , \mathbf{X} , \mathbf{X} , \mathcal{X} , \mathbf{x} are all different symbols possibly referring to different entities.

This is a very short paragraph.

This is a longer paragraph (notice the blank line in the code). It is composed of several sentences. You're invited to use comments within .tex source files to separate sentences composing the same paragraph.

Paragraph should be logically atomic: a subordinate sentence from one paragraph should always refer to another sentence from within the same paragraph.

The first line of a paragraph is usually indented. This is intended: it is the way L^AT_EX lets the reader know a new paragraph is beginning.

Use the `listing` package for inserting scripts into the L^AT_EX source.