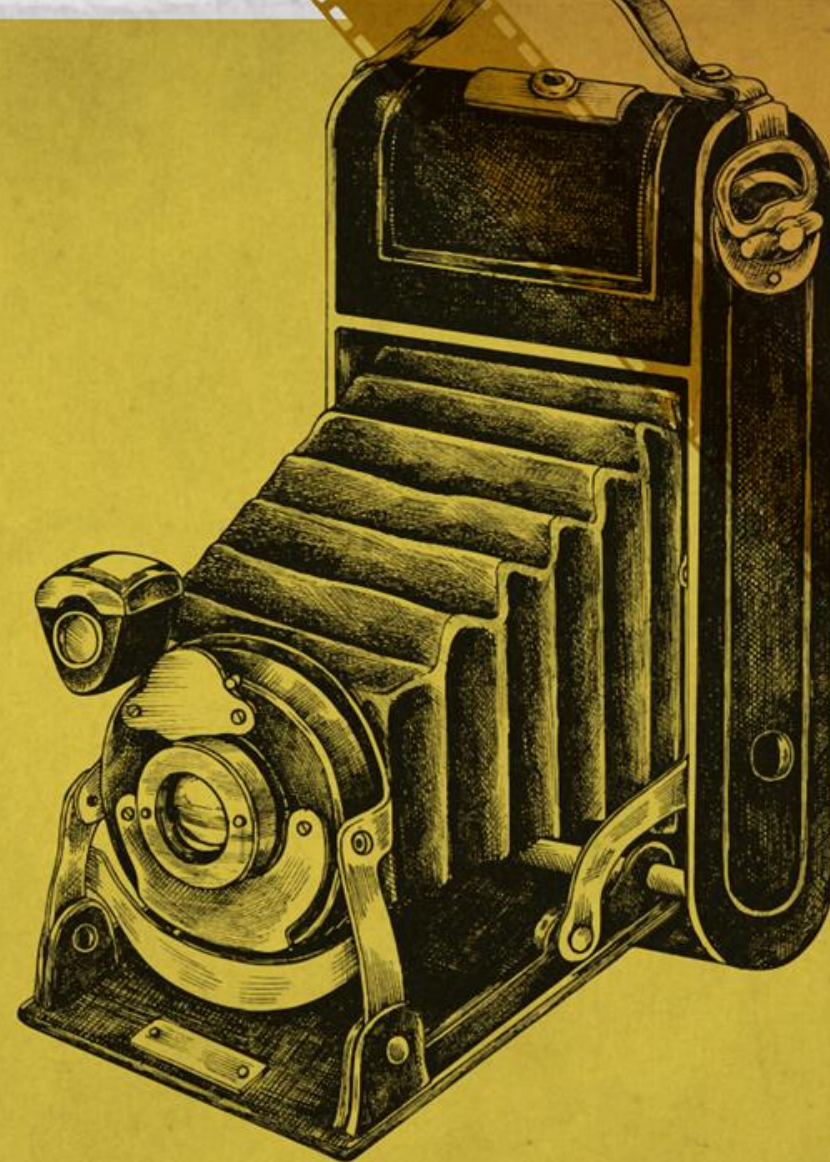
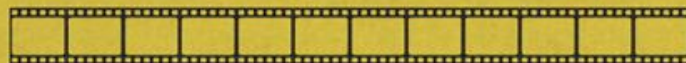




25<sup>TH</sup> MAY / 2022 ◊ VALENCIA, SPAIN

## FINAL WORKSHOP

The NEMOSINE innovative  
package for cultural  
heritage preservation



More info at: [nemosineproject.eu](https://nemosineproject.eu)



NEMOSINE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 760801.





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# *Sensors and wireless solutions for Cultural Heritage preservation*

Ioannis Kakogiannos



Abeer Al Mohtar



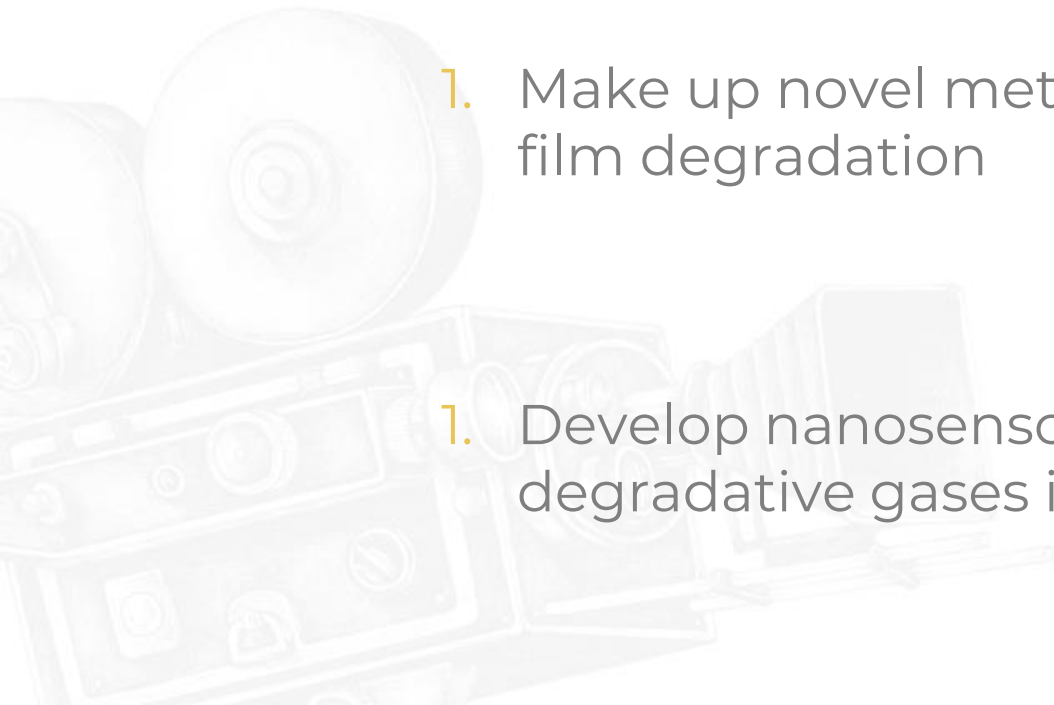
Federico Ortenzi





# *Conservation of cellulose derivatives-based artifacts*

1. Study of the degradation mechanisms of cinematographic film
1. Make up novel methodologies for remote monitoring of film degradation
1. Develop nanosensors for high-sensitivity monitoring of degradative gases involved in CH deterioration



# *Volatiles involved in films deterioration*

Water-dependent reaction:

Cellulose n-acetate + water  $\rightarrow$  cellulose (n-1) acetate + **acetic acid**

Autocatalytic reaction:

Cellulose n-acetate + acetic acid  $\rightarrow$  cellulose (n-1) acetate + 2 **acetic acid**



# *Conservation of cellulose derivatives-based artifacts*

Detection methods targeting acetic acid

Innovative solutions

Conventional solution

- ❑ AD STRIP with a LOD of 0.75ppm

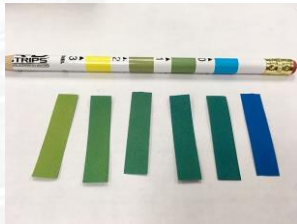


Fig.1 AD strip

- ❑ Photoluminescence-based ZnO nanorods/PANI
- ❑ Metal oxide semiconductor (MOS) resistance-based sensors

# Photoluminescent detection based on nanostructured ZnO-Polyaniline

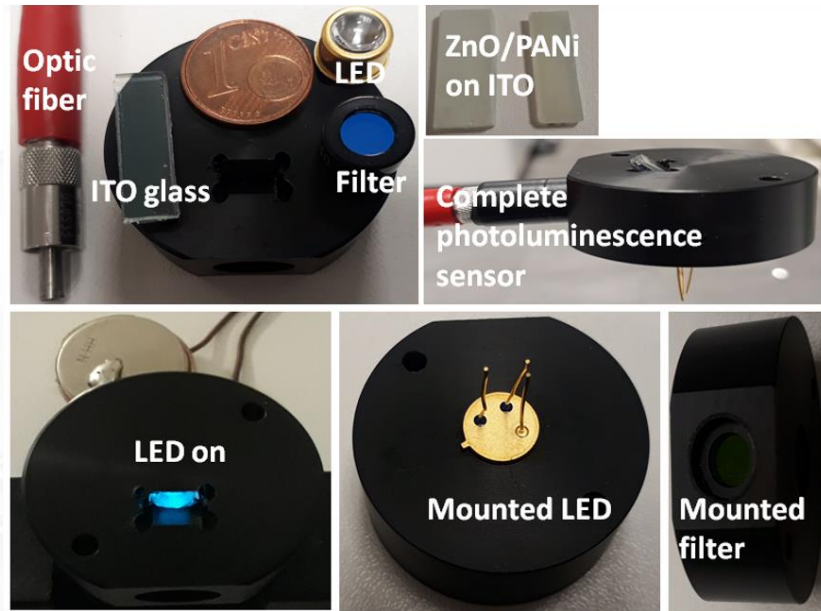


Fig.2 Components and assembly of the sensor  
(Turemis *et al.*, 2020)

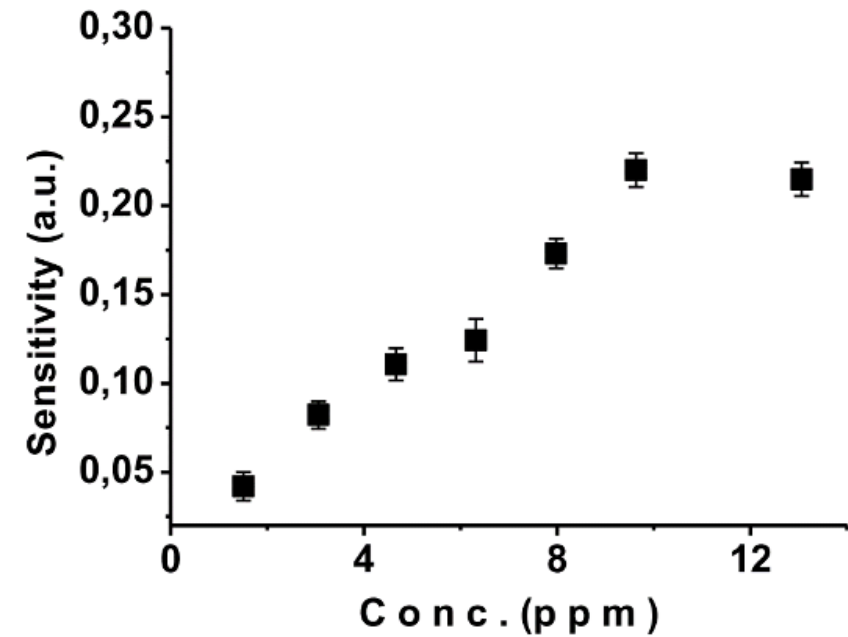


Fig.3 Linearity range (1-10 ppm)  
(Turemis *et al.*, 2020)



# *PANI Nanostructured Sensors*

Good selectivity, reversibility, works at RT, linearity 1-10ppm



Does not overcome sensitivity of AD strip



Miniaturization



Power demand



Cost

# *Metal oxide semiconductor-based sensors*

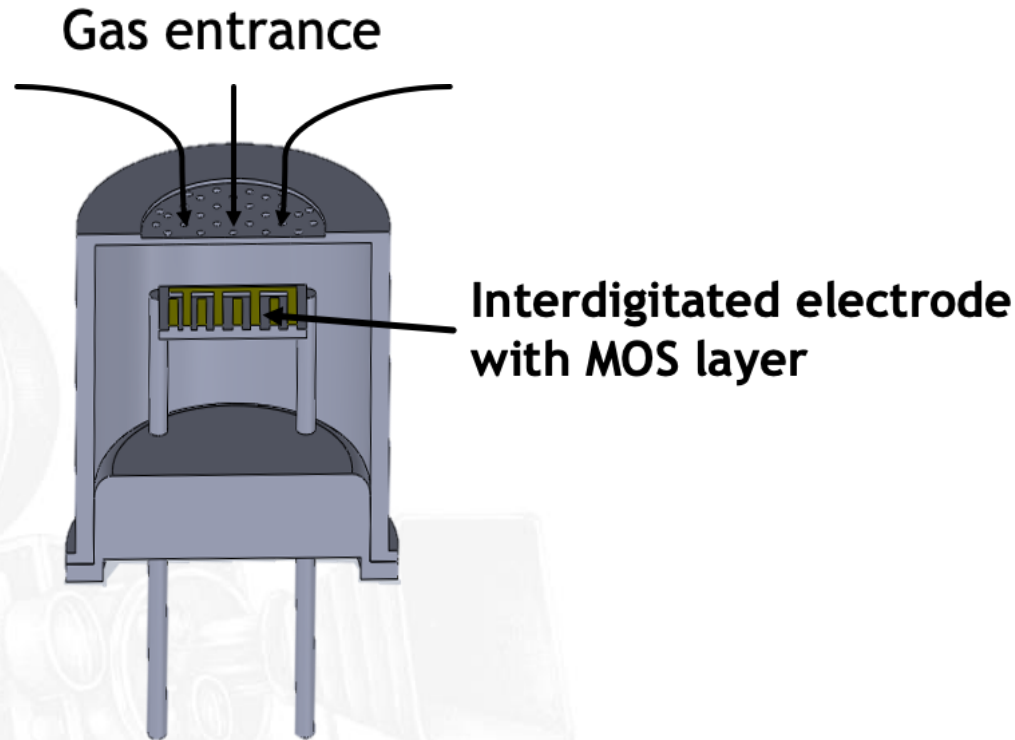


FIG.4 MOS sensor



FIG.5 Representative interdigitated electrode surface



# *MOS board array*

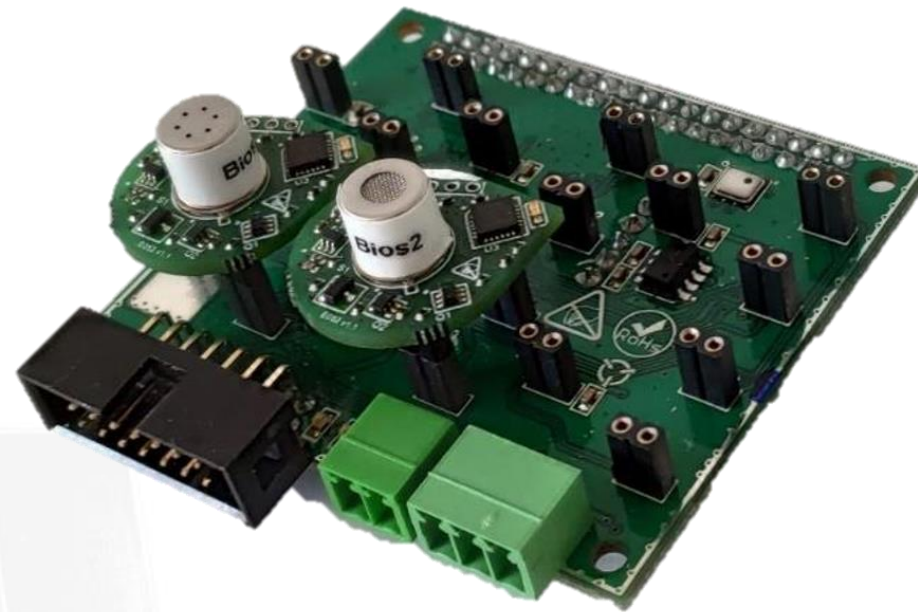


FIG. 6 Final sensor arrangement

# Data interpolation

Algorithm written and applied to integrate data coming from the two sensors.

Accurate determination of Acetic Acid concentration, independently from other interferent gasses

*Vpasolve* (symbolic package)

```

10 for i=1:n
11 Eqn = ( A(i) - 40206*x^(-0.442))/(597373*x^(-0.592)-40206*x^(-0.442)) == ( B(i) - 56128*x^(-0.322))/(411714*x^(-0.484)-56128*x^(-0.322));
12 X = vpasolve(Eqn, x, 100000);
13 alfa1 (i) = (A(i) - 40206*X^(-0.442))/(597373*X^(-0.592)-40206*X^(-0.442));
14 alfa2 (i) = (B(i) - 56128*X^(-0.322))/(411714*X^(-0.484)-56128*X^(-0.322));

```

FIG. 7 Code extract

# Sensor functionality

Overcome  
sensitivity of AD  
strip

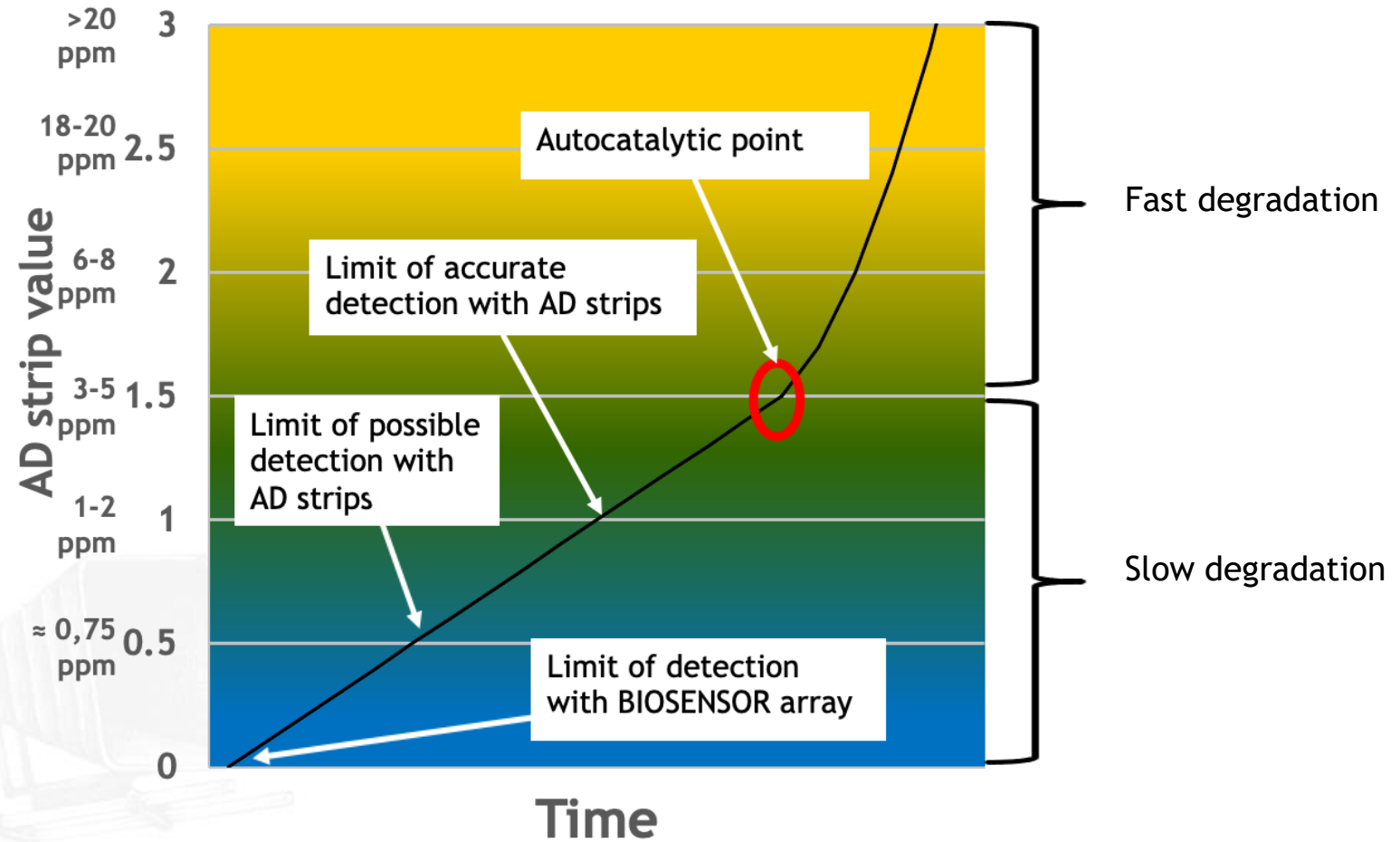
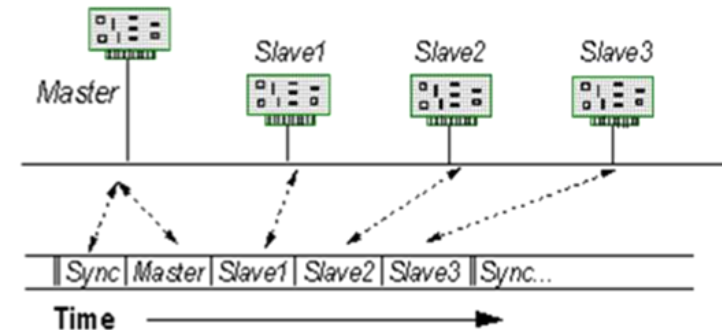
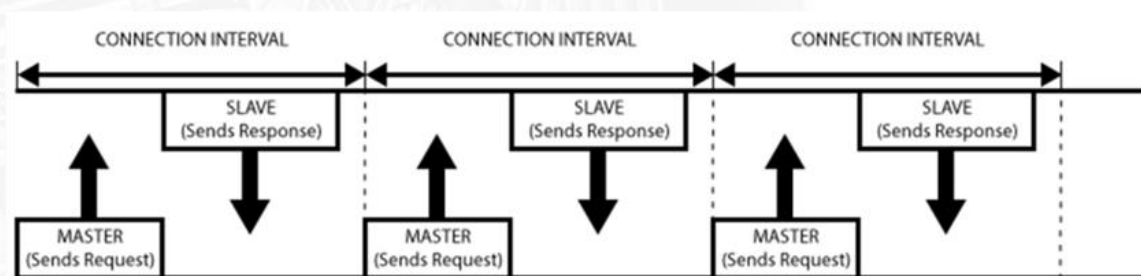
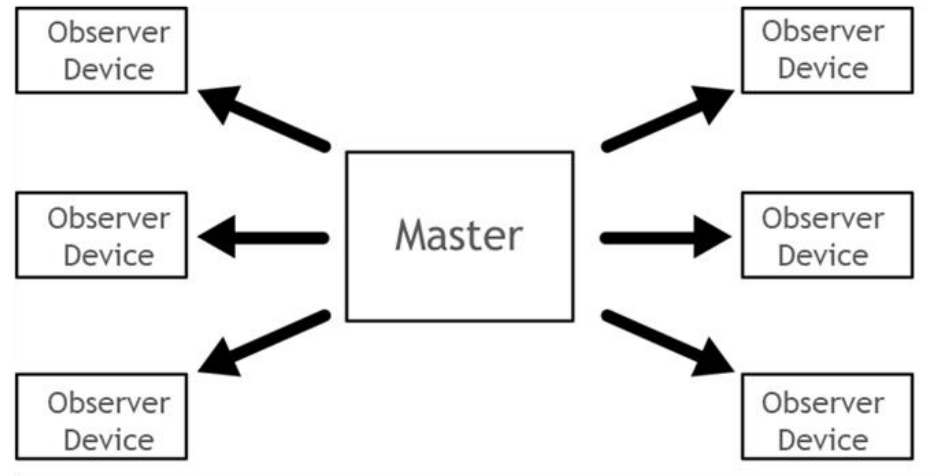


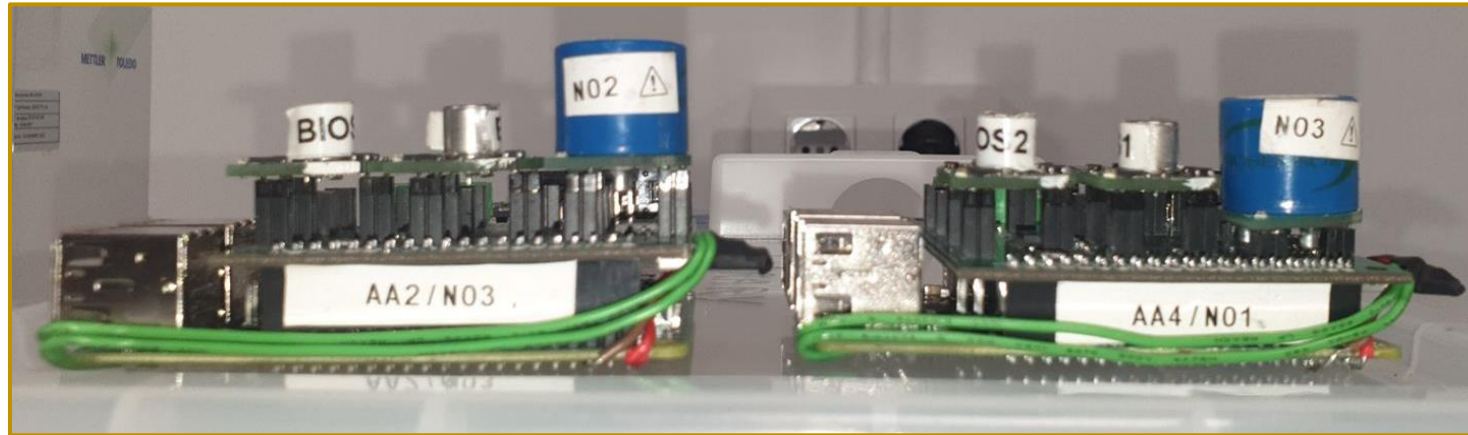
FIG. 8 AA sensing levels



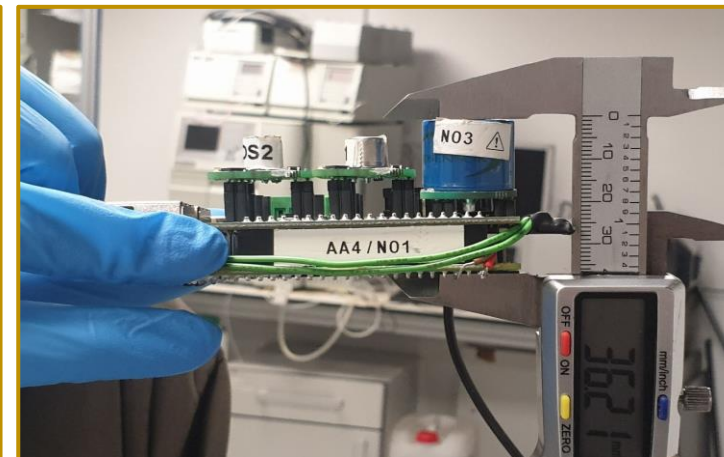
# Wireless Sensor Network (WSN)



# Wireless Sensor Network (WSN)



AA&N02 PCB  
43mm



Modified PCB  
(size reduction)  
36mm

# Wireless Sensor Network (WSN) Endurance and Acceptance tests



WSN Testing and Calibration



# Wireless Sensor Network (WSN) Deployment preparations



- 1- Power Source
- 2- Local Network Modem
- 3- AA/NO<sub>2</sub> Node
- 4- Master Node
- 5- Ambient T&H Node



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# Wireless Sensor Network (WSN) Validations set-up





# Control platform development

As a Film user in desktop app:

- Register and edit a Media
- Assign media to a shelf or to a SPU
- Simulate the degradation of media
- Calculate the degree of substitution to be used by the prediction model
- Analyse AA and NO<sub>2</sub> data in chart
- Export sensors data to CSV file

The screenshot displays the Nemosine desktop application interface, which is organized into several panels:

- Top Bar:** Includes the Nemosine logo, an "UPLOAD" button with a folder icon, and a "LOGOUT" button with a right arrow icon.
- ACETIC ACID PREDICTION:** Features a line graph showing "Nondegraded" (y-axis, 0.0 to 100.0) versus "Age" (x-axis, 0.0 to 60.0). A purple curve starts at 100.0 and drops sharply after age 40. Below the graph is a "DEGREE OF SUBSTITUTION" section with a "DS MODE" dropdown set to "Automat", a "DS VALUE" slider set to 2.00, and "Calculate DS" and "Cancel" buttons.
- ACETIC ACID HISTORY:** Shows a line graph of "Acetic acid" (y-axis, 5000.0 to 10000.0) over time. The data points show a fluctuating upward trend.
- IDENTIFICATION:** Contains fields for "TITLE" (In eurer Hand\_MOFs), "ID.NUMBER" (24135100), "CARRIER" (Film, 35 mm), "ELEMENT TYPE" (Print, 0), "EXTENT" (0), "STATUS" (-), "SOUND" (Type, Fixation), "SYSTEM" (Status), "SPECIFICATIONS" (Company, Year 2022, Colour, Standard), "MASS OF THE FILM (KG)" (1.95), "CHAMBER VOLUME (CM³)" (1,000.00), "AD-STRIP" (1.00), "CONDITION" (Surface), and "IMAGE" (Decomp.).
- SENSOR:** Displays sensor data for "DATE RECORD" (2022/05/13 10:57:07), "NO<sub>2</sub>" (-0.03 ppb, STAGI Fresh Film), "ACETIC ACID" (6256.22 ppb, STAGI Increasing De), "TEMP" (12.6 °C, RH 56%), "LEVEL" (-0.03 ppb), "CLASSIFICATION" (Fresh Film), "ACETIC ACID" (Level 6256.22 ppb, Classification Increasing Degradation), and "ROOM" (Temperature 12.6 °C, RH 56%). An "Export measurements" button is at the bottom.
- Room A:** Shows "SHELF Node B" (Films: 3, Node: green square) and "SPU SPU1" (Films: 0, Node: white square).

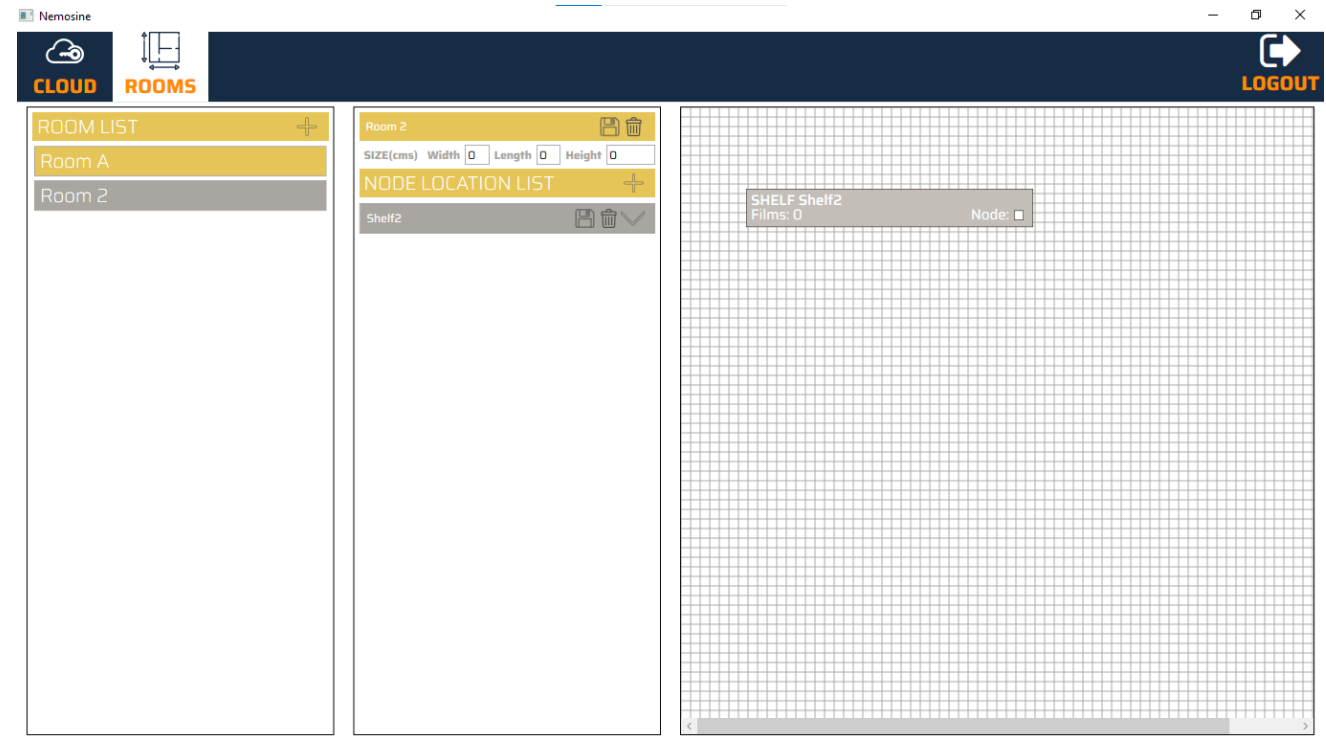




# Control platform development

As Technician user in desktop app:

- Register rooms
- Register shelves
- Register SPUs
- Assign sensors to rooms and SPUs





## FINAL WORKSHOP:

The NEMOSINE innovative package and solutions for 20th century cultural heritage preservation.

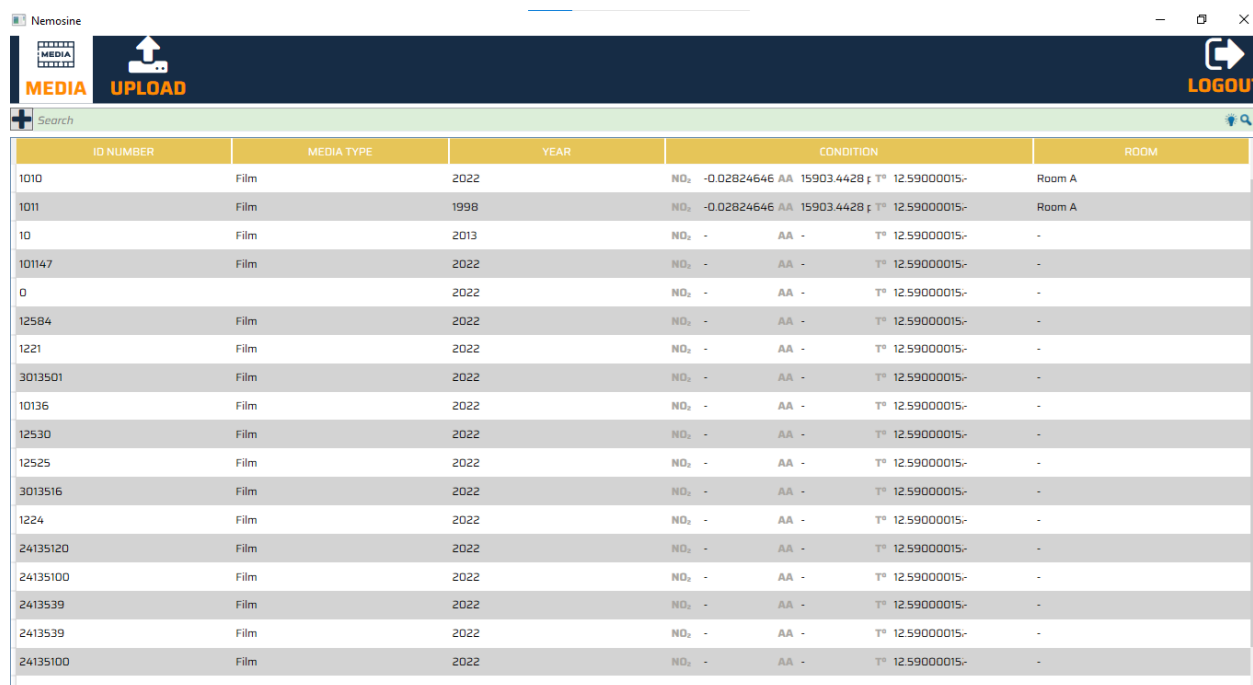


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# Control platform development

As Film Store user in desktop app:

- List of medias previously registered
- Send measurements from sensors anonymously to the cloud
- Automatic download of models uploaded by Film Makers in the cloud application



The screenshot shows the Nemosine desktop application interface. At the top, there is a dark blue header bar with the 'NEMOSINE' logo on the left, an 'UPLOAD' button with an upward arrow icon in the center, and a 'LOGOUT' button with a rightward arrow icon on the right. Below the header is a light green search bar with a magnifying glass icon. The main content area displays a table with the following columns: ID NUMBER, MEDIA TYPE, YEAR, CONDITION, and ROOM. The table contains 19 rows of data, all of which are 'Film' type. The 'CONDITION' column contains a complex string of values including 'NO<sub>2</sub>', 'AA', and 'T<sup>°</sup>'. The 'ROOM' column mostly contains 'Room A' or '-'.

ID NUMBER	MEDIA TYPE	YEAR	CONDITION	ROOM
1010	Film	2022	NO <sub>2</sub> -0.02824646 AA 15903.4428 f T <sup>°</sup> 12.59000015-	Room A
1011	Film	1998	NO <sub>2</sub> -0.02824646 AA 15903.4428 f T <sup>°</sup> 12.59000015-	Room A
10	Film	2013	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
101147	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
0		2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
12584	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
1221	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
3013501	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
10136	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
12530	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
12525	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
3013516	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
1224	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
24135120	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
24135100	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
2413539	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
2413539	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-
24135100	Film	2022	NO <sub>2</sub> - AA - T <sup>°</sup> 12.59000015-	-

Showing 0-19 of 19 items



# *Control platform development*

As Model Maker user in cloud app:

- Download anonymized measurements from the data submitted by archives
- Upload updated models to be used in the desktop application by archives

## Measurements download

Note: for convenience, change the extension of the downloaded file to ".csv".



DOWNLOAD MEASUREMENTS

## Model Upload

Drag and drop file  
here

or

🔍 Browse for file



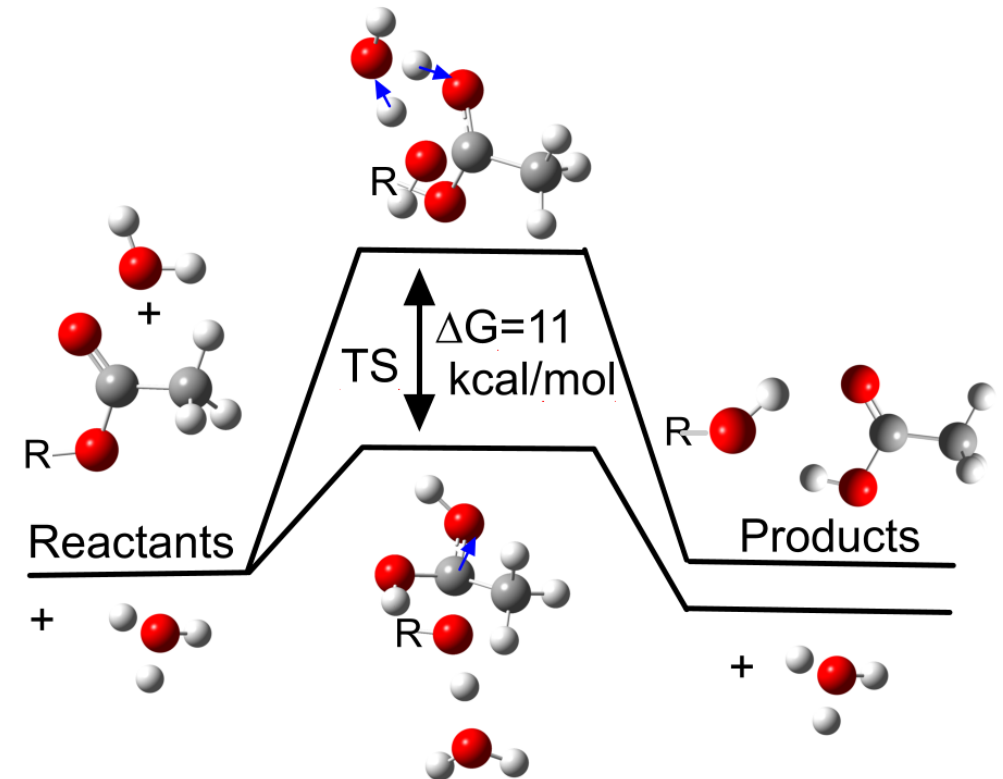
# First-principles Model – Cellulose acetate pure polymer

✓ Molecular modelling to determine the Gibbs free energy of activation for the two main degradation channels [1]:

- Water-hydrolysis under neutral conditions.
- Acid-catalysed hydrolysis.

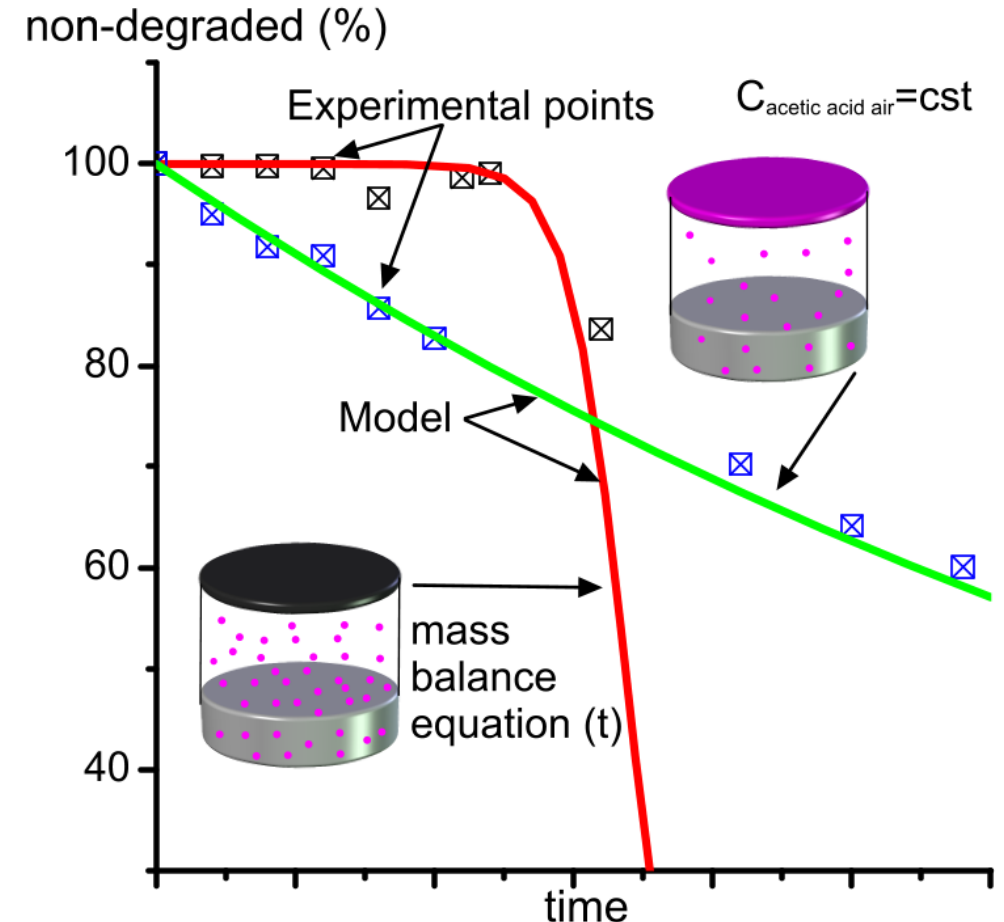
Acid catalyzed degradation channel is **> 8 orders of magnitude faster** than that of deacetylation under neutral conditions

[1] A. Al Mohtar, S. Nunes, J. Silva, A. M. Ramos, J. Lopes, and M.L. Pinto. "First-Principles Model to Evaluate Quantitatively the Long-Life Behavior of Cellulose Acetate Polymers." **ACS omega** 6, no. 12 (2021): 8028-8037.



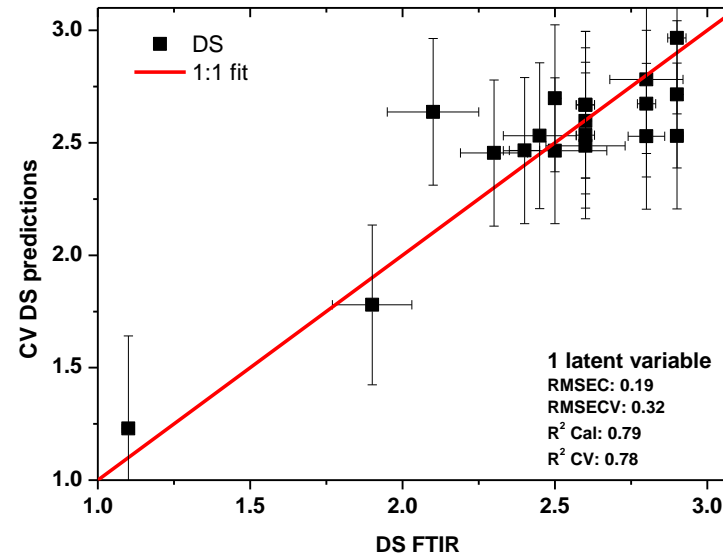
# First-principles Model – Cellulose acetate pure polymer

- ✓ Transition state theory to calculate the kinetic behaviour of the cellulose acetate polymer as function of ambient conditions (T, RH, acetic acid concentration,..)
- ✓ Account for the acetic acid volatility:
  - Measure the Henry's constant of the cellulose acetate polymer and use the mass balance equation
- ✓ Accelerated aging experiments to validate the model.

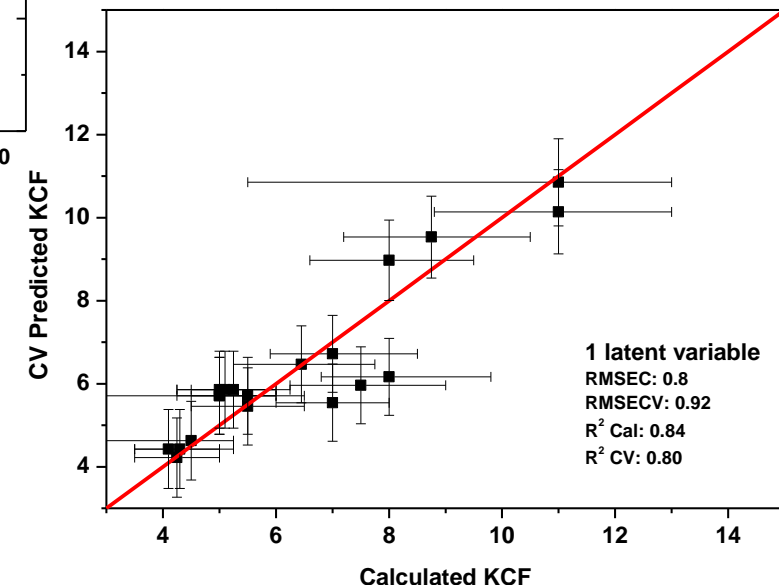


# Hybrid Model – Cellulose acetate-based movie films

- ✓ Models built with a 29-film-database
- ✓ Model to predict the degree of substitution based on gas data and user input information [2].
- ✓ Model to predict how much faster each movie film is degradation based on user input information [2].



- ✓ Models validated upon introducing a new set of known films, accuracy > 85%.



[2] Abeer Al Mohtar, et al. "Decision making based on hybrid modeling approach applied to cellulose acetate based historical films conservation". *Scientific Reports*. 2021.

<https://doi.org/10.1038/s41598-021-95373-0>




# User interface



ROOMS SHELVES MEDIA

010219-135036

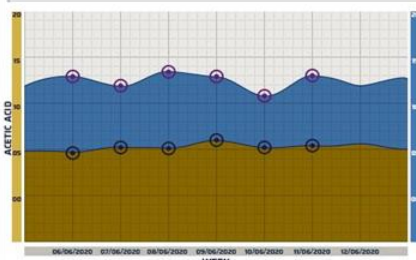


CURATOR  
Ernest Prost

ARCHIVE 010219 FILM N° 135036

STATUS Poor COPY N° 09

REVISION



**IDENTIFICATION**

TITLE  
Metropolis

ID.NUMBER 135036 LOCATION 010213-032595

**CARRIER**

TYPE Film SPECIFIC 35 mm

**ELEMENT TYPE**

TYPE Duplicate UNITS 5

EXTENT 35 mts STATUS MASTER

**SOUND**

TYPE Sound FIXATION Magnetic

SYSTEM Combined BASE Nitrate

**SPECIFICATIONS**

COMPANY Kodak YEAR 01/01/1929

COLOUR Tinted STANDARD Pathecolor

**CONDITION**

CONDITION Film&Video SURFACE Rust

IMAGE Faded DECOMPO. Sticky

SHRINKAGE 75% LAST DATE 2003-07-15

**RELATIONSHIP**

Ernest Prost

EVENTS

OTHER RELATIONSHIP

**SENSOR**

DATE RECORD 05/03/2020

NOx 15ppm STAGE Fresh Film

ACETIC ACID 0,8 ppm STAGE Increasing D

TEMP 16° Celsius RH 23%

**NOx**

LEVEL 15 ppm

CLASSIFICATION Fresh Film

**ACETIC ACID**

LEVEL 0,8 ppm

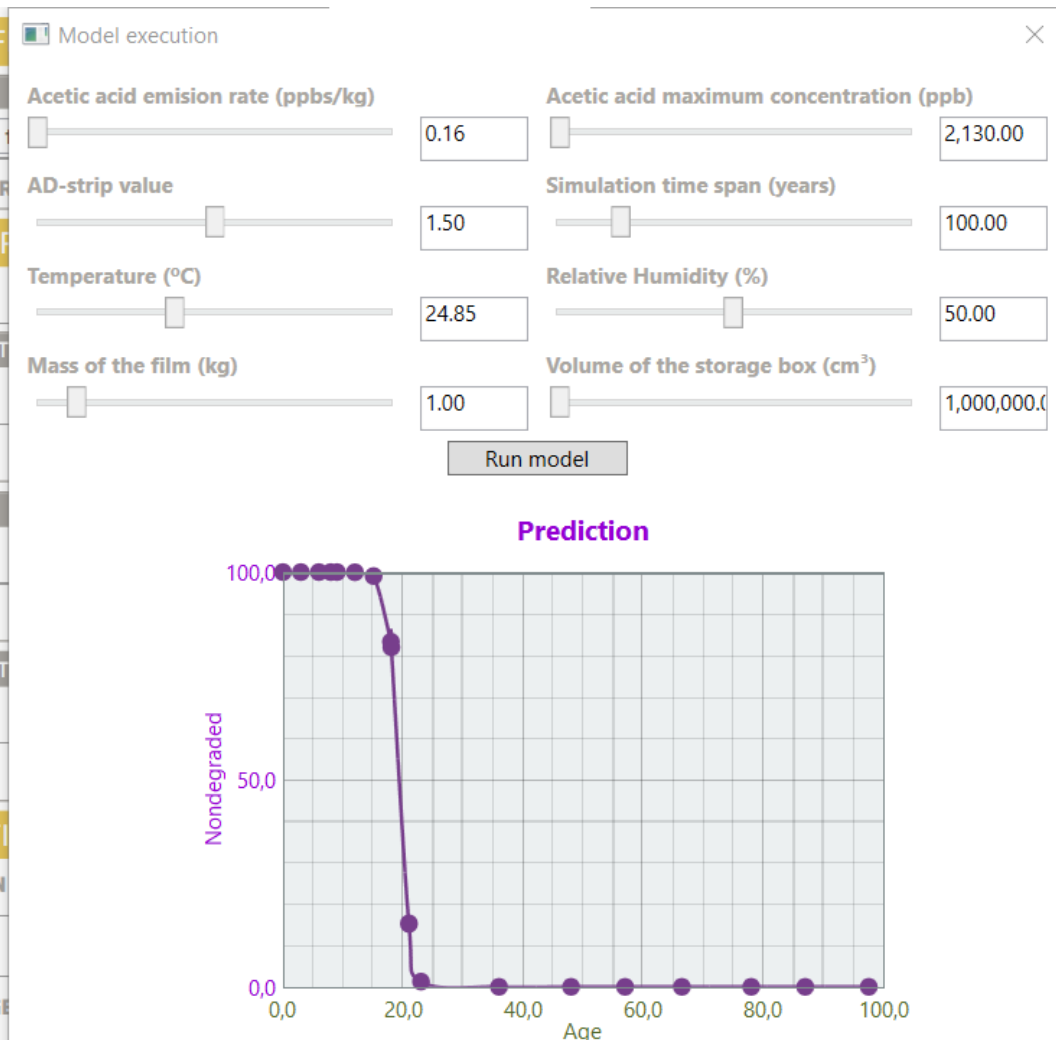
CLASSIFICATION Increasing Degradation

**ROOM**

ID 011697AB STATUS OnLine

TEMPERATURE 16° Celsius

RH 23% RH





# Results

Realization of platform that answer to cost-effectiveness, miniaturization, low power-demand and long-term stability for the accurate detection of Acetic Acid at much lower levels when compared to AD STRIPS

Real-time monitoring allows intervention in real time to prevent film loss and to allow conservation intervention

Arrays are suitable for integration in conservation boxes and were tested both in laboratory and in conservation institutes part of the consortium





# THANKS TO

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DFF team (Film selection & info):

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More info at: [nemosineproject.eu](http://nemosineproject.eu)



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# THANKS FOR YOUR ATTENTION

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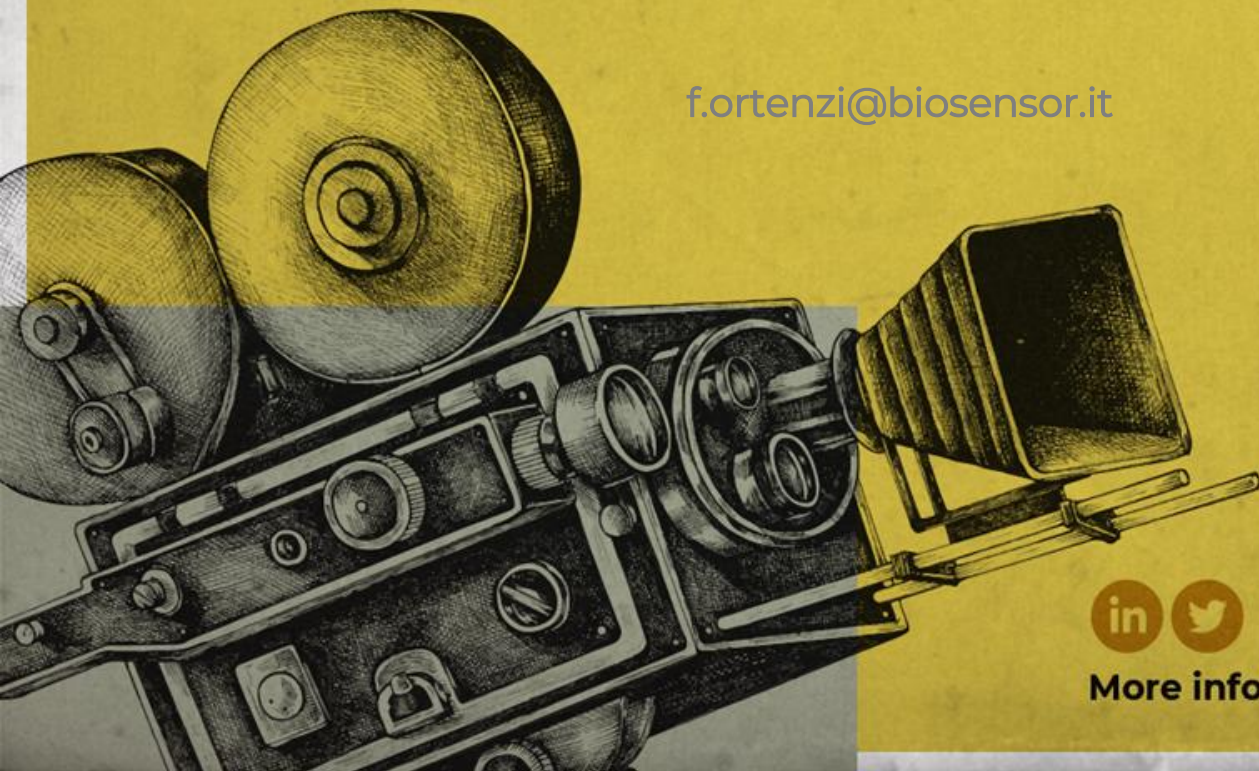
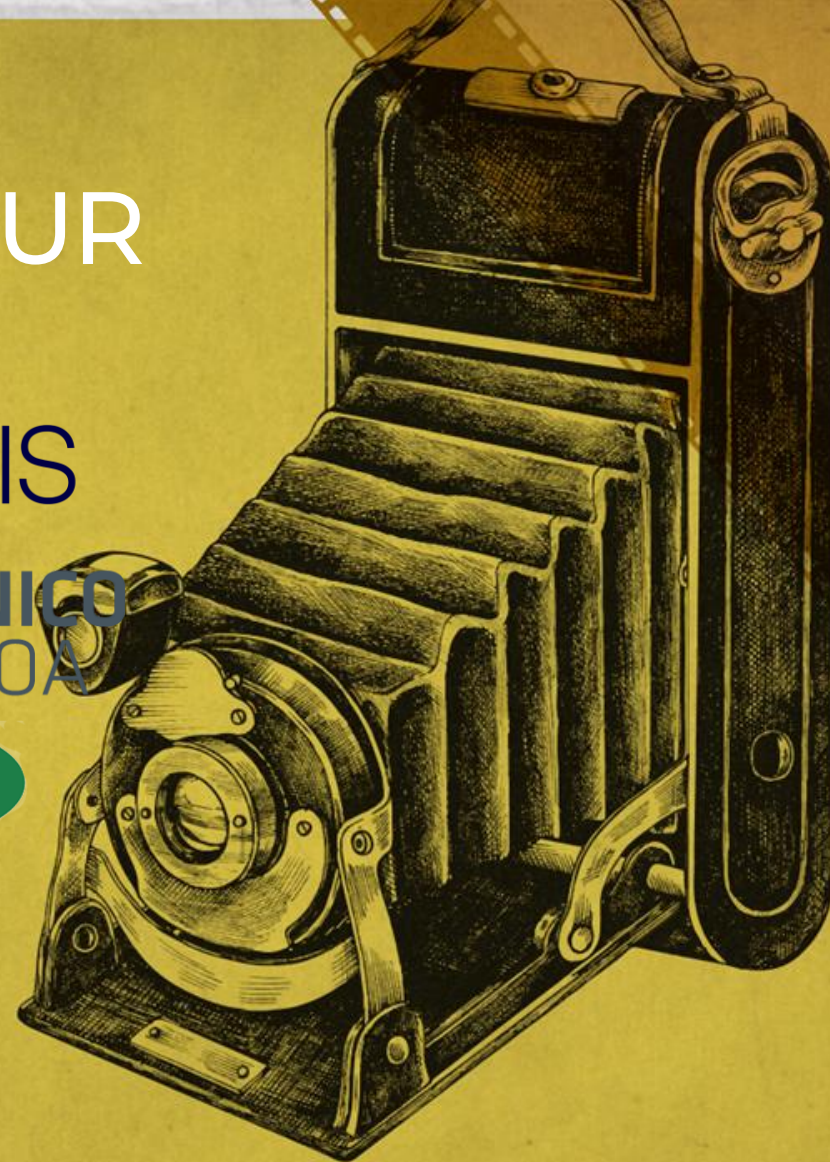


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