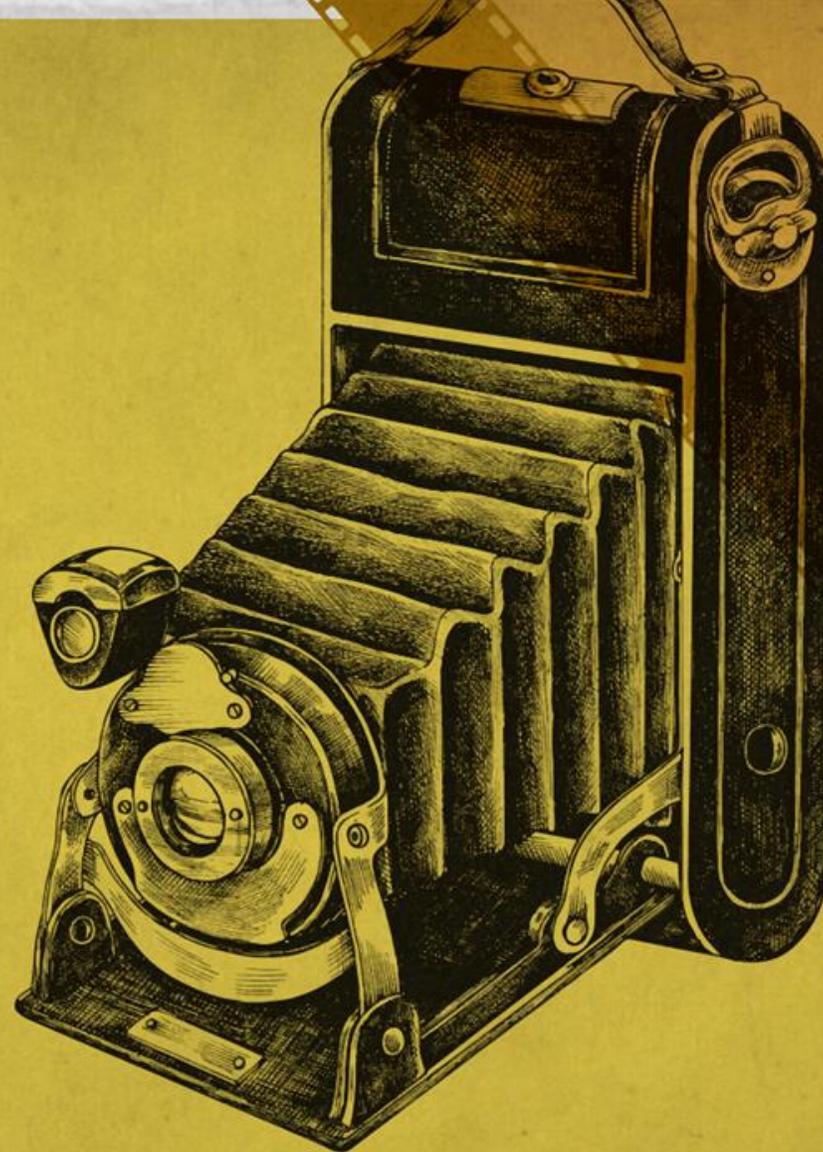
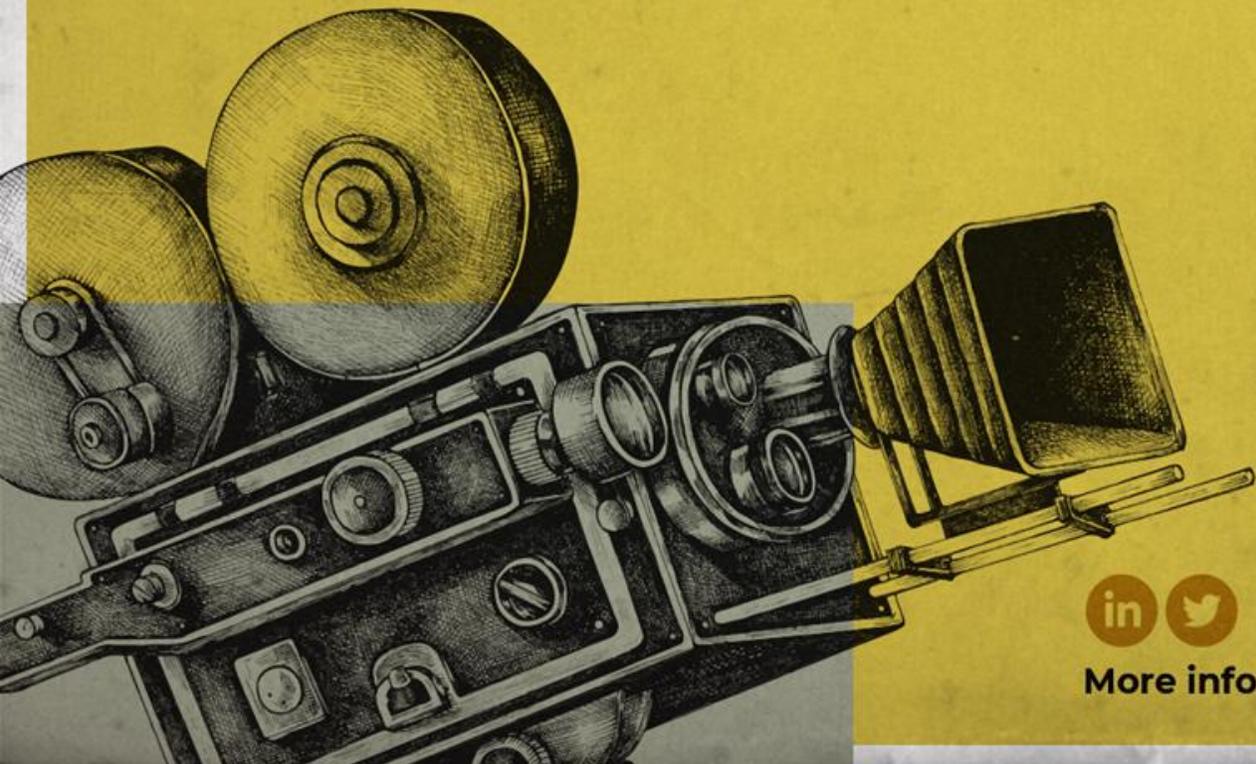
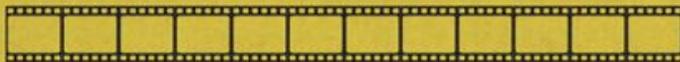


25<sup>TH</sup> MAY / 2022 ◊ VALENCIA, SPAIN

## 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



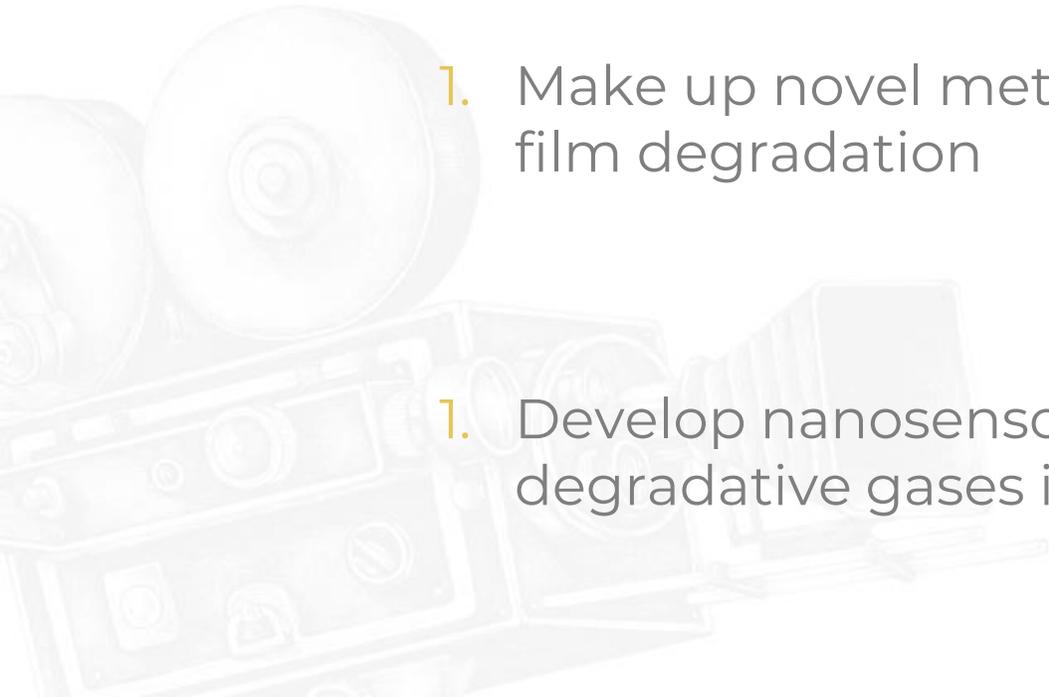
Federico Ortenzi





# *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

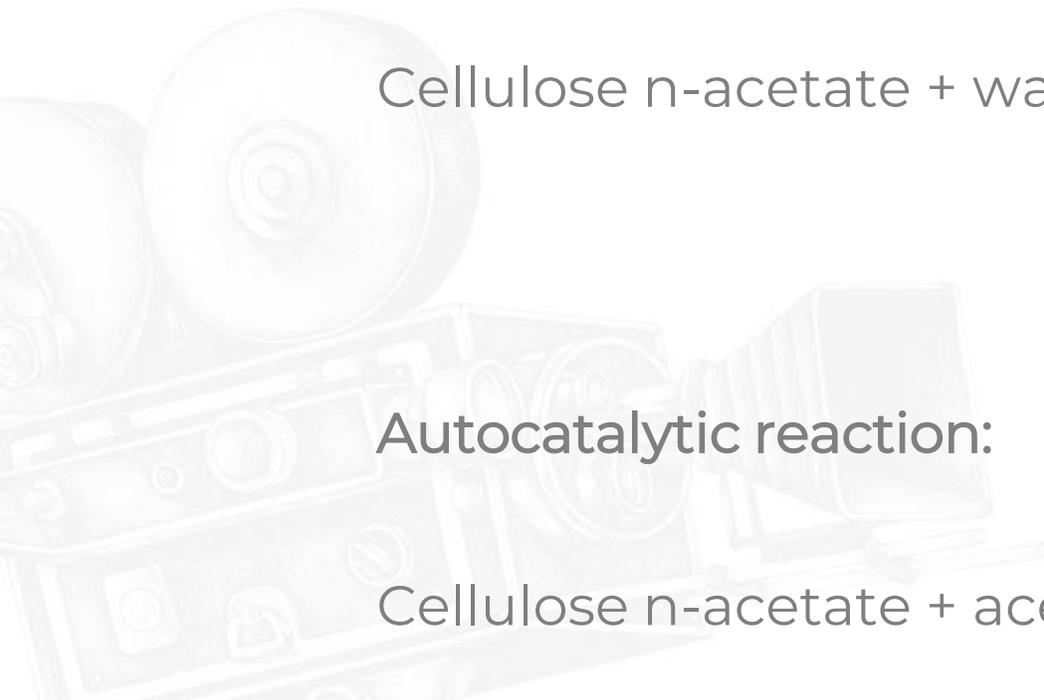


# *Volatiles involved in films deterioration*

Water-dependent reaction:



Autocatalytic reaction:



# *Conservation of cellulose derivatives-based artifacts*

Detection methods targeting acetic acid

## Conventional solution

- ❑ AD STRIP with a LOD of 0.75ppm

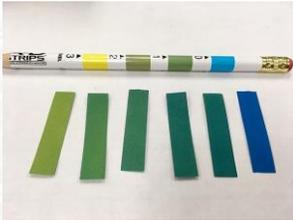


Fig.1 AD strip

## Innovative solutions

- ❑ 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)

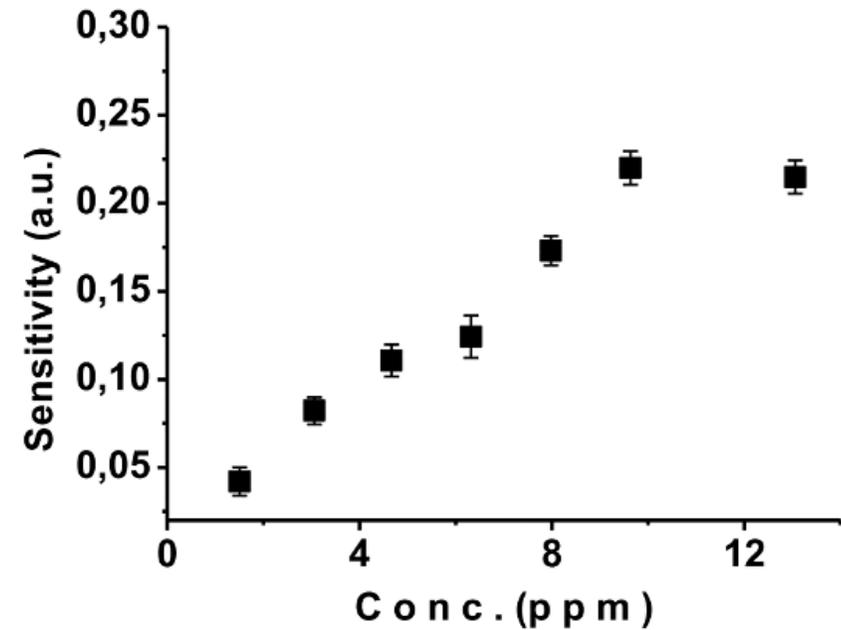


Fig.3 Linearity range (1-10 ppm)  
(Turemis *et al.*, 2020)



# *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*

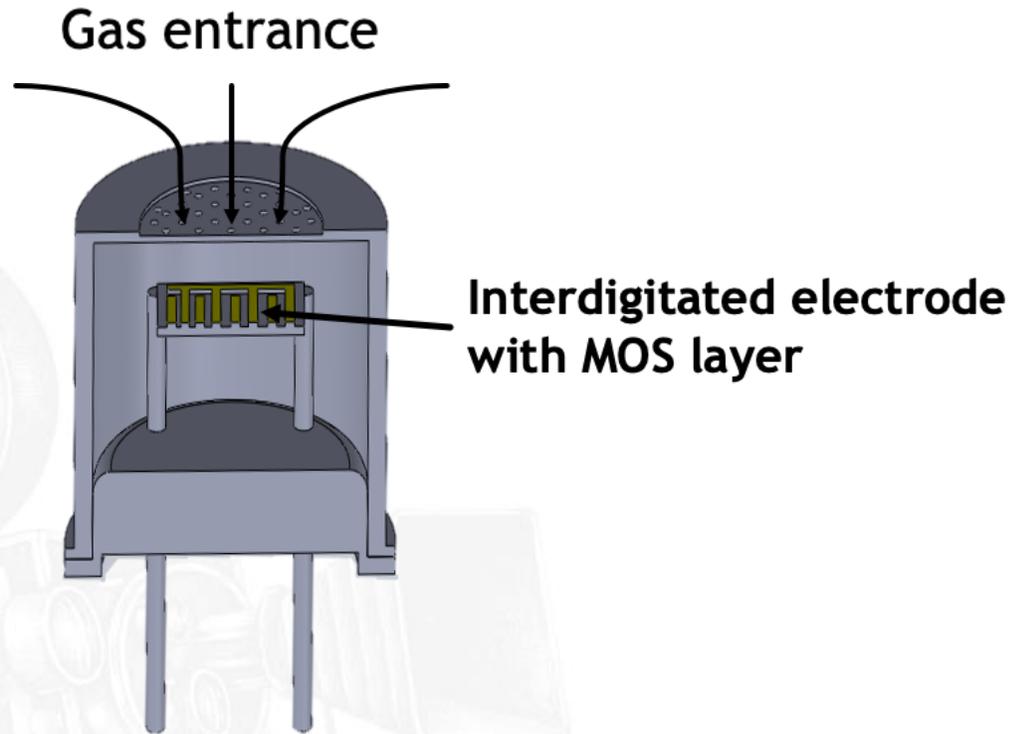


FIG.4 MOS sensor

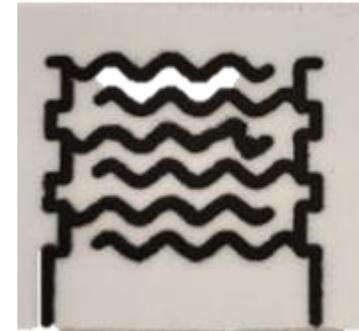


FIG.5 Representative interdigitated electrode surface

# *MOS board array*

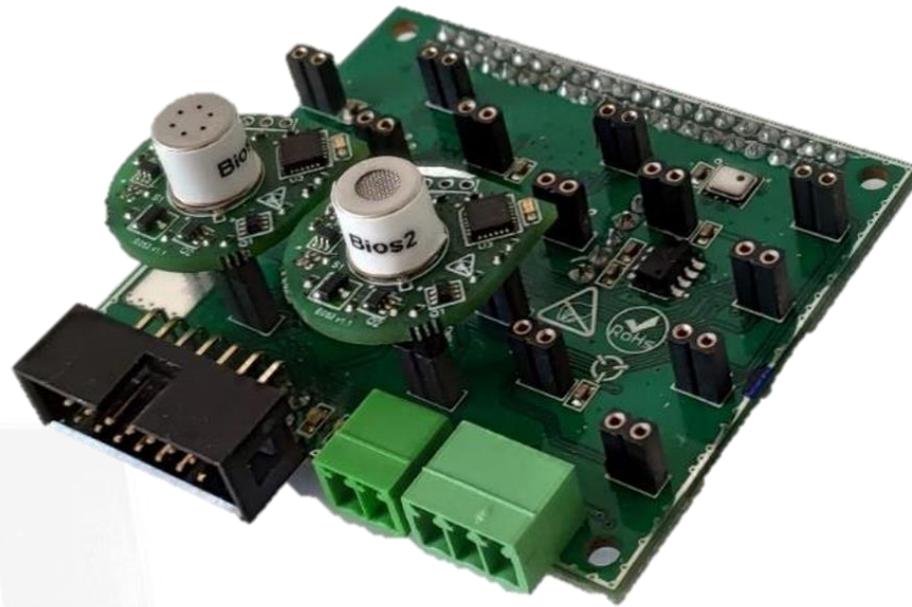


FIG. 6 Final sensor arrangement

# 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

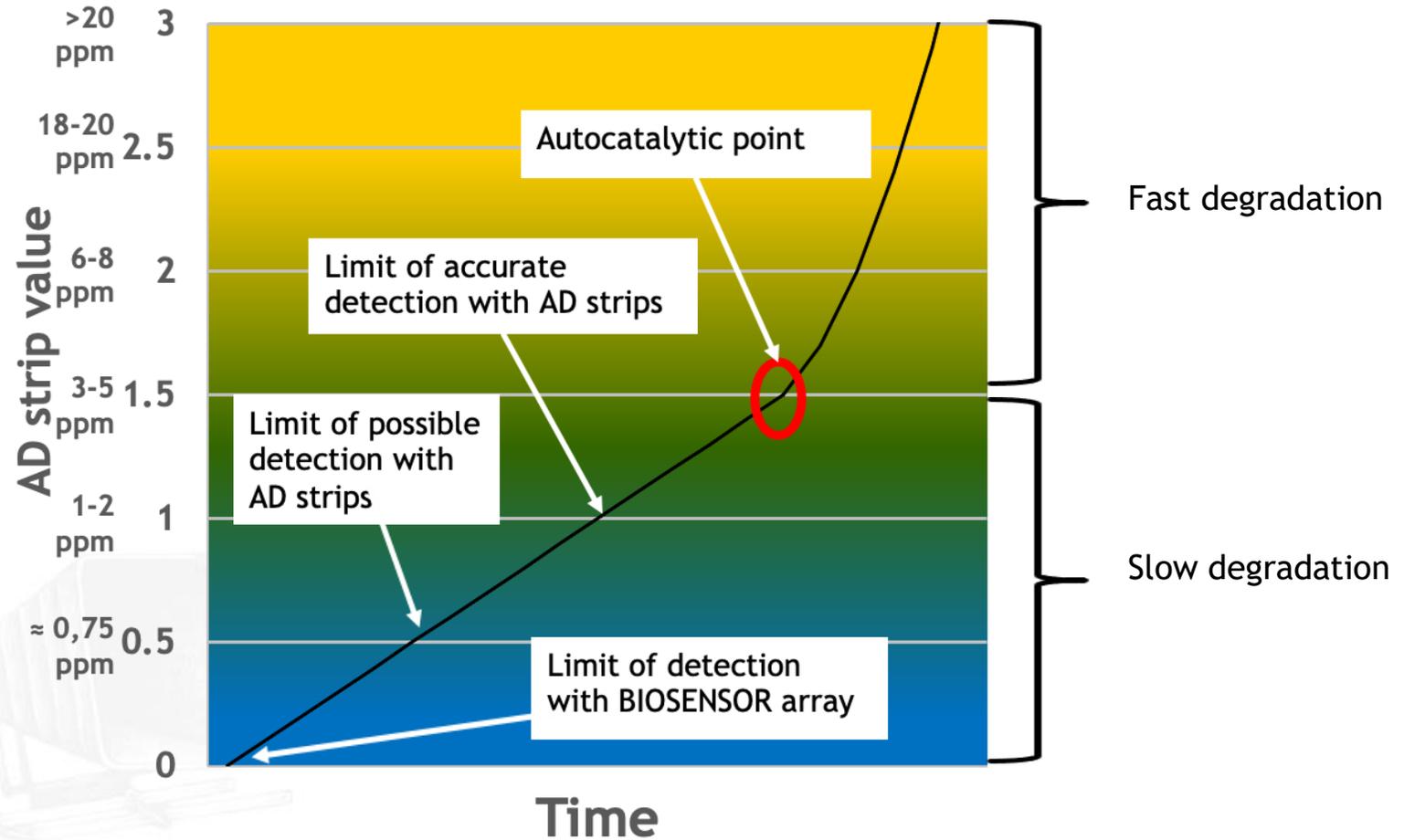
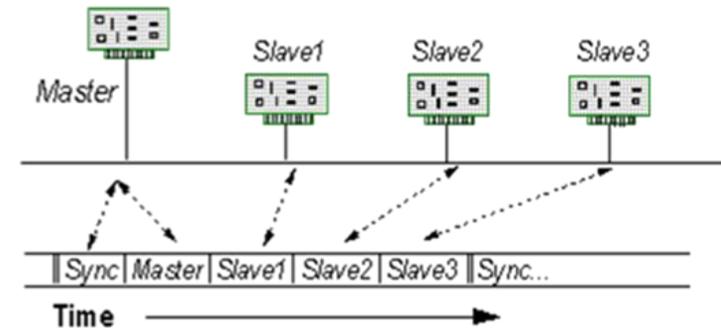
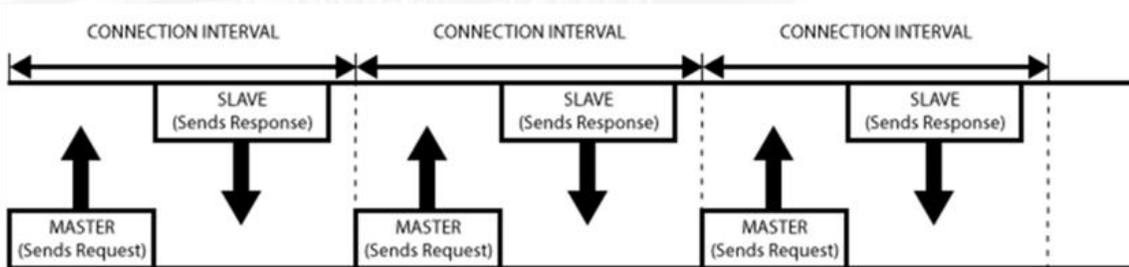
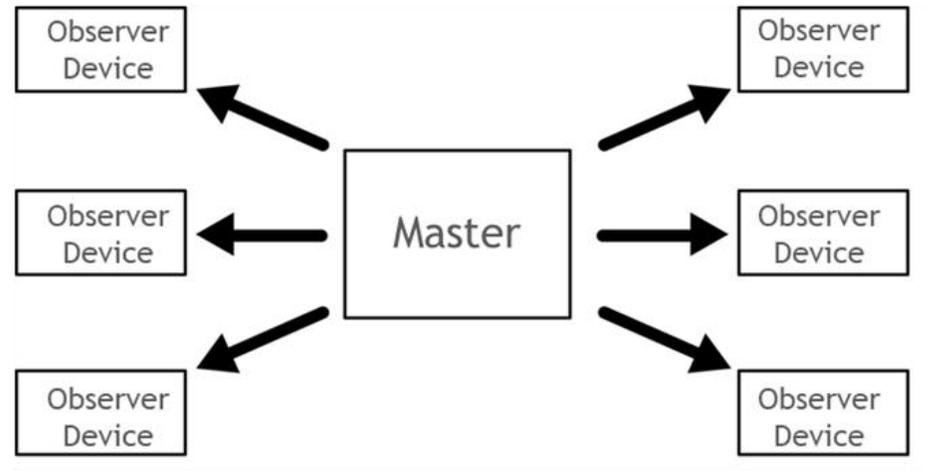


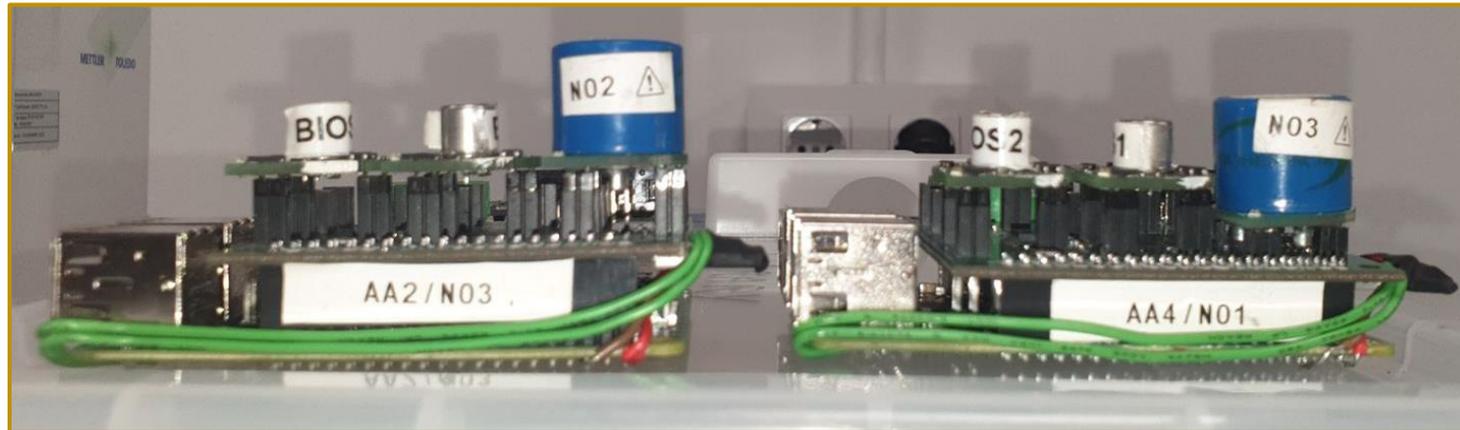
FIG. 8 AA sensing levels

# Wireless Sensor Network (WSN)





# Wireless Sensor Network (WSN)



AA&NO2 PCB  
43mm



Modified PCB  
(size reduction)  
36mm



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# 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 divided into several functional panels:

- Top Bar:** Includes a 'MEDIA UPLOAD' button with an upload icon and a 'LOGOUT' button with a right-pointing arrow.
- ACETIC ACID PREDICTION:** Features a line graph showing 'Prediction' of 'Nondegraded' percentage over 'Age' (0.0 to 60.0). The curve starts at 100.0 and drops to approximately 20.0 at age 60. Below the graph is a 'DEGREE OF SUBSTITUTION' section with a 'DS MODE' dropdown set to 'Automat' and a 'DS VALUE' slider set to 2.00. 'Calculate DS' and 'Cancel' buttons are present.
- ACETIC ACID HISTORY:** Shows a line graph of 'Acetic acid' levels over time, with values ranging from 0 to 10000.0.
- IDENTIFICATION:** A form containing fields for 'TITLE' (In eurer Hand\_MOFs), 'ID.NUMBER' (24135100), 'CARRIER' (Film, SPECIFIC, 35 mm), 'ELEMENT TYPE' (Print, UNITS: 0), 'SOUND' (TYPE: -, FIXATION: -), 'SYSTEM' (TYPE: -, STATUS: -), and 'SPECIFICATIONS' (COMPANY, YEAR: 2022, COLOUR, STANDARD, MASS OF THE FILM (KG): 1.95, CHAMBER VOLUME (CM<sup>3</sup>): 1,000.000, AD-STRIP: 1.00).
- SENSOR:** Displays real-time sensor data for 'Room A', including '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%), and 'ROOM' (TEMPERATURE: 12.6°C, RH: 56%). An 'Export measurements' button is located at the bottom.
- Room A Panel:** Shows 'SHELF Node B' (Films: 3, Node: ) and 'SPU SPU1' (Films: 0, Node: ) with a grid for monitoring.



## FINAL WORKSHOP:

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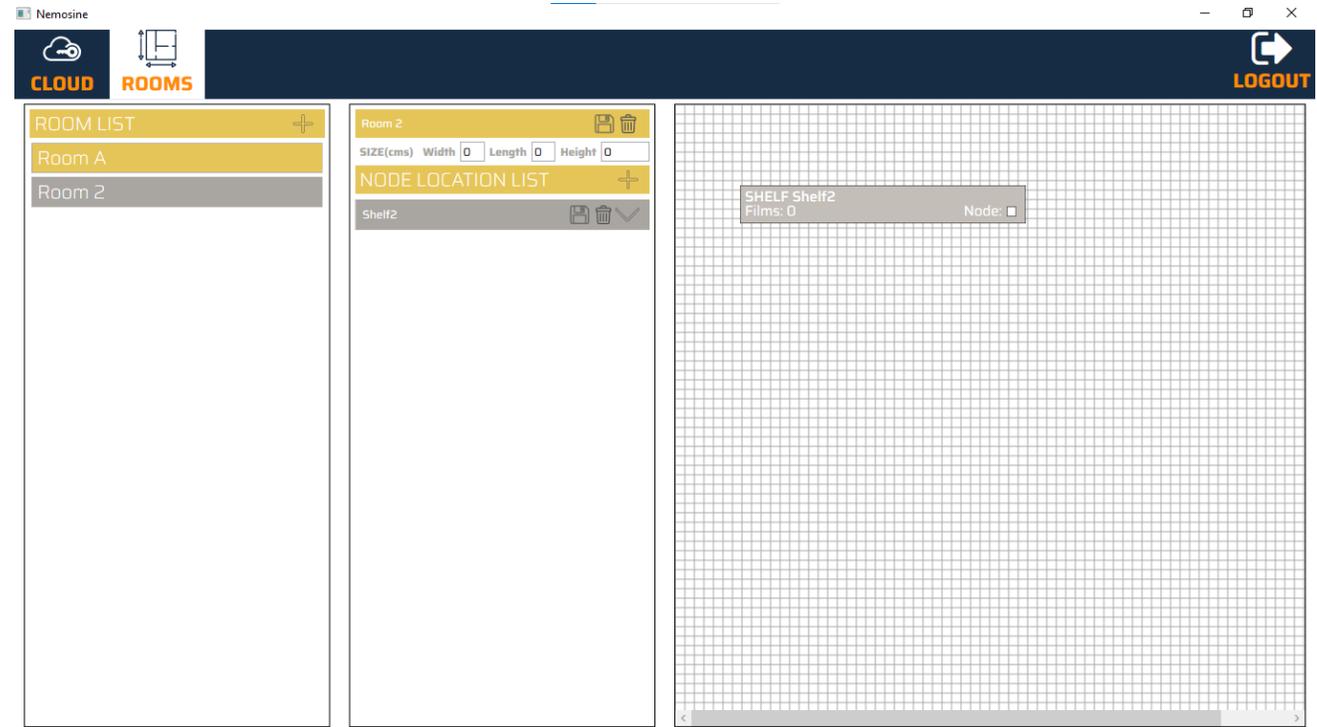


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# Control platform development

As Technician user in desktop app:

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





# 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 with the 'NEMOSINE' logo, an 'UPLOAD' button with an upward arrow icon, and a 'LOGOUT' button with a rightward arrow icon. Below the header is a 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' items. The 'CONDITION' column contains technical specifications for each item. The 'ROOM' column shows 'Room A' for the first two items and '-' for the others. At the bottom of the table, it says 'Showing 0-19 of 19 items'.

ID NUMBER	MEDIA TYPE	YEAR	CONDITION	ROOM
1010	Film	2022	ND <sub>s</sub> -0.02824646 AA 15903.4428 ; T <sup>o</sup> 12.59000015-	Room A
1011	Film	1998	ND <sub>s</sub> -0.02824646 AA 15903.4428 ; T <sup>o</sup> 12.59000015-	Room A
10	Film	2013	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
101147	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
0		2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
12584	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
1221	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
3013501	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
10136	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
12530	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
12525	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
3013516	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
1224	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
24135120	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
24135100	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
2413539	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
2413539	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-
24135100	Film	2022	ND <sub>s</sub> - AA - T <sup>o</sup> 12.59000015-	-





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# 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

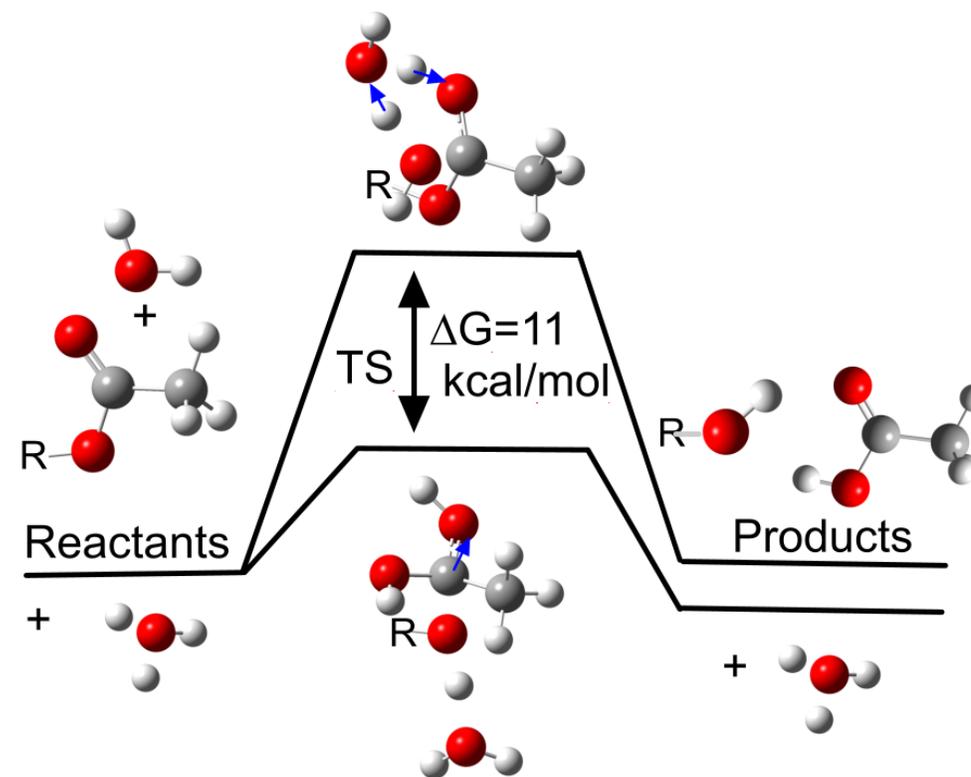
 [Browse for file](#)

# 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.

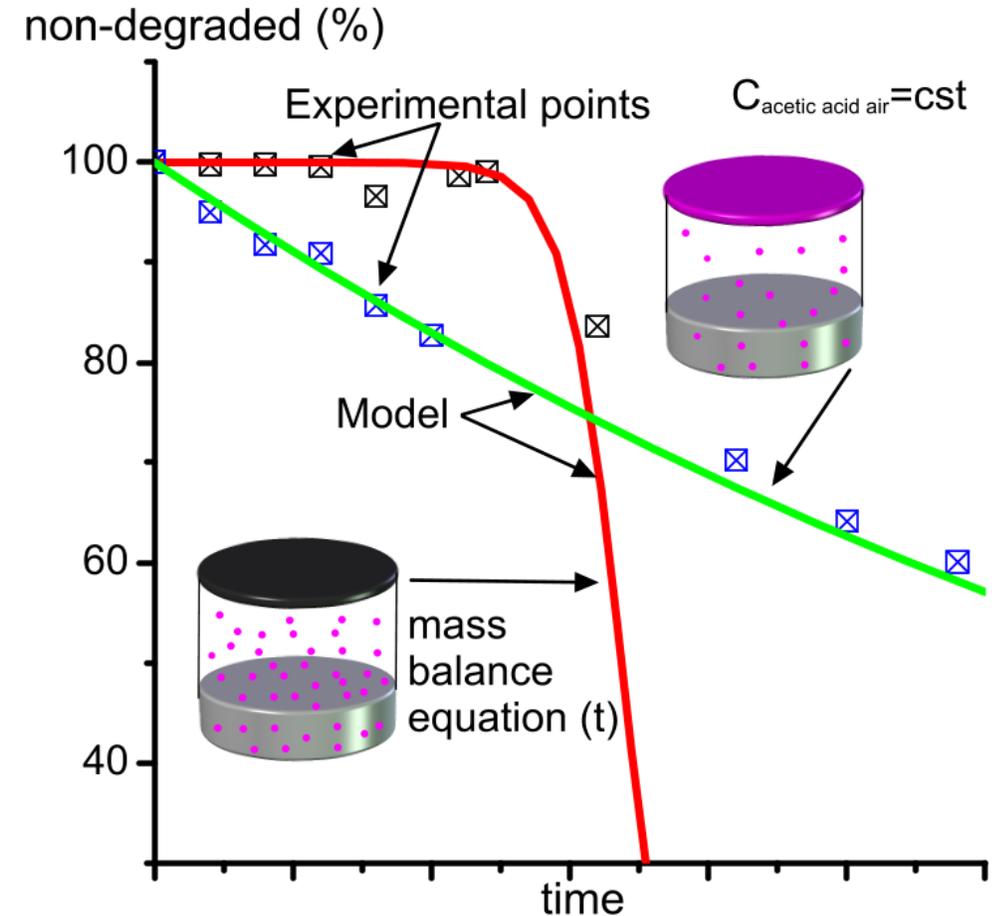
Acid catalyzed degradation channel is **> 8 orders of magnitude faster** than that of deacetylation under neutral conditions



[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

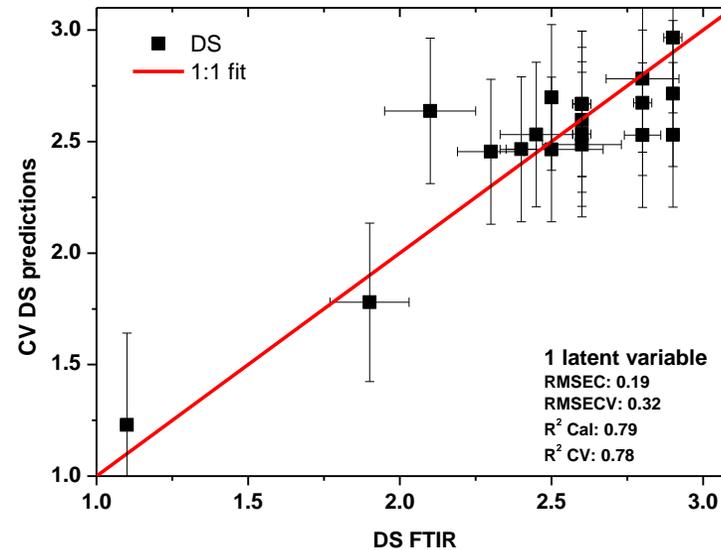
- ✓ Transition state theory to calculate the kinetic behaviour of the cellulose acetate polymer as function of ambient conditions (T, RH, acetic acid concentration,..)
- ✓ Account for the acetic acid volatility:
  - Measure the Henry's constant of the cellulose acetate polymer and use the mass balance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



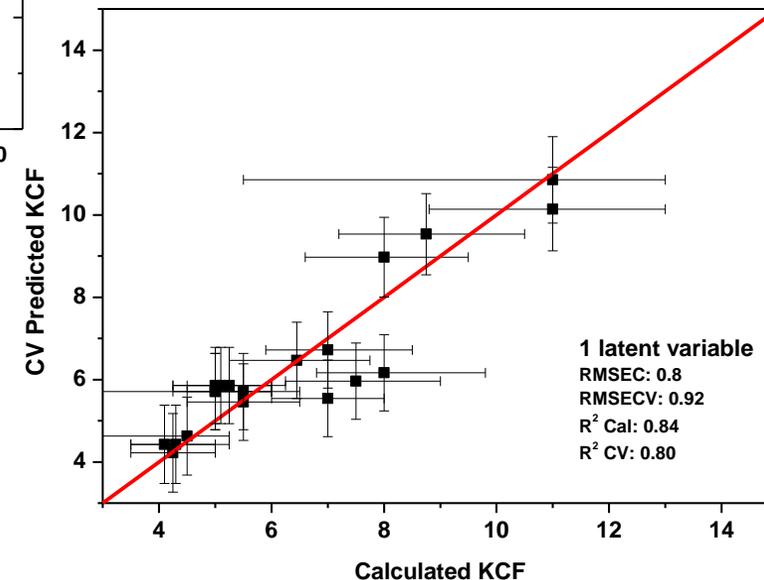


# Hybrid Model – Cellulose acetate-based movie films

- ✓ 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**

Model execution

Acetic acid emission rate (ppbs/kg)

Acetic acid maximum concentration (ppb)

AD-strip value

Simulation time span (years)

Temperature (°C)

Relative Humidity (%)

Mass of the film (kg)

Volume of the storage box (cm<sup>3</sup>)

Run model

**Prediction**



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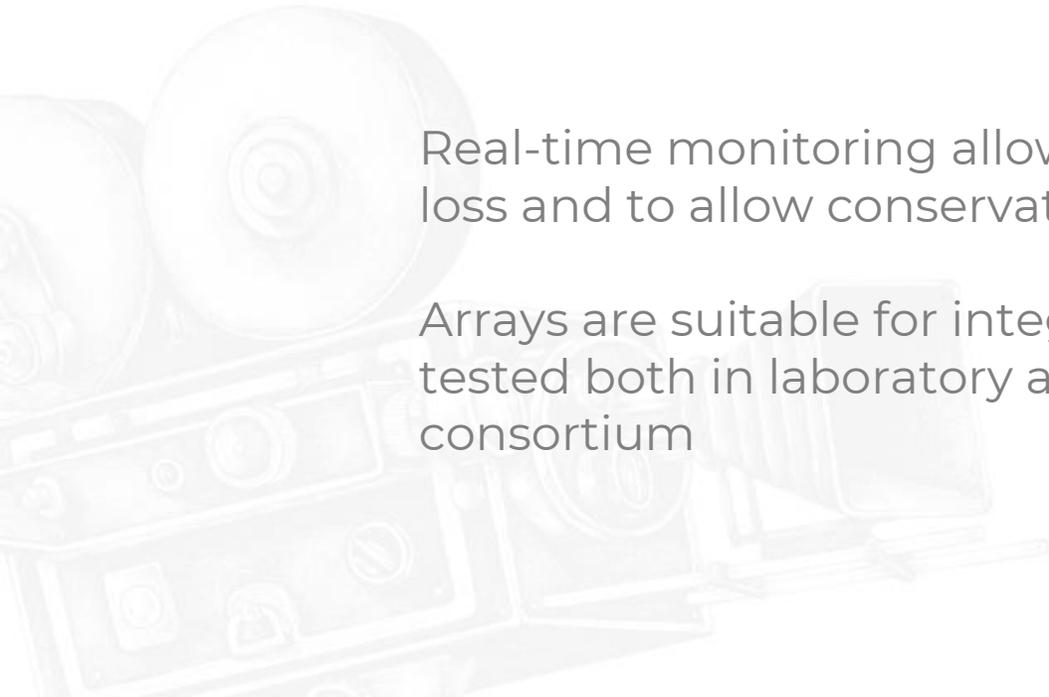
NEMOSINE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 760801.

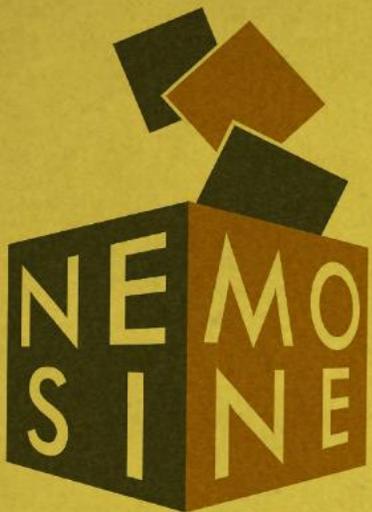
# Results

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

Ulisboa team (Modeling):

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*João Lopes* [jlopes@ff.ulisboa.pt](mailto:jlopes@ff.ulisboa.pt)

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OAEW team (Film selection and information):

*Nadja Wallaszkovits* [Nadja.Wallaszkovits@oeaw.ac.at](mailto:Nadja.Wallaszkovits@oeaw.ac.at)

DFF team (Film selection & info):

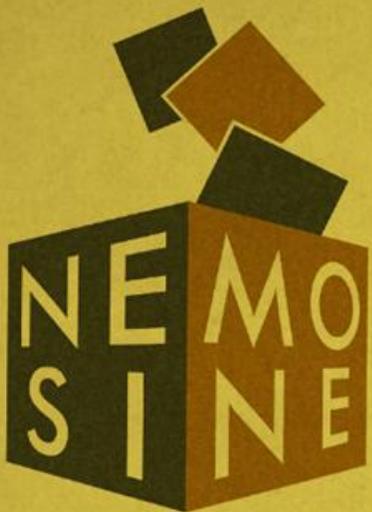
*Kerstin Herlt* [Herlt@dff.film](mailto:Herlt@dff.film)



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



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# THANKS FOR YOUR ATTENTION

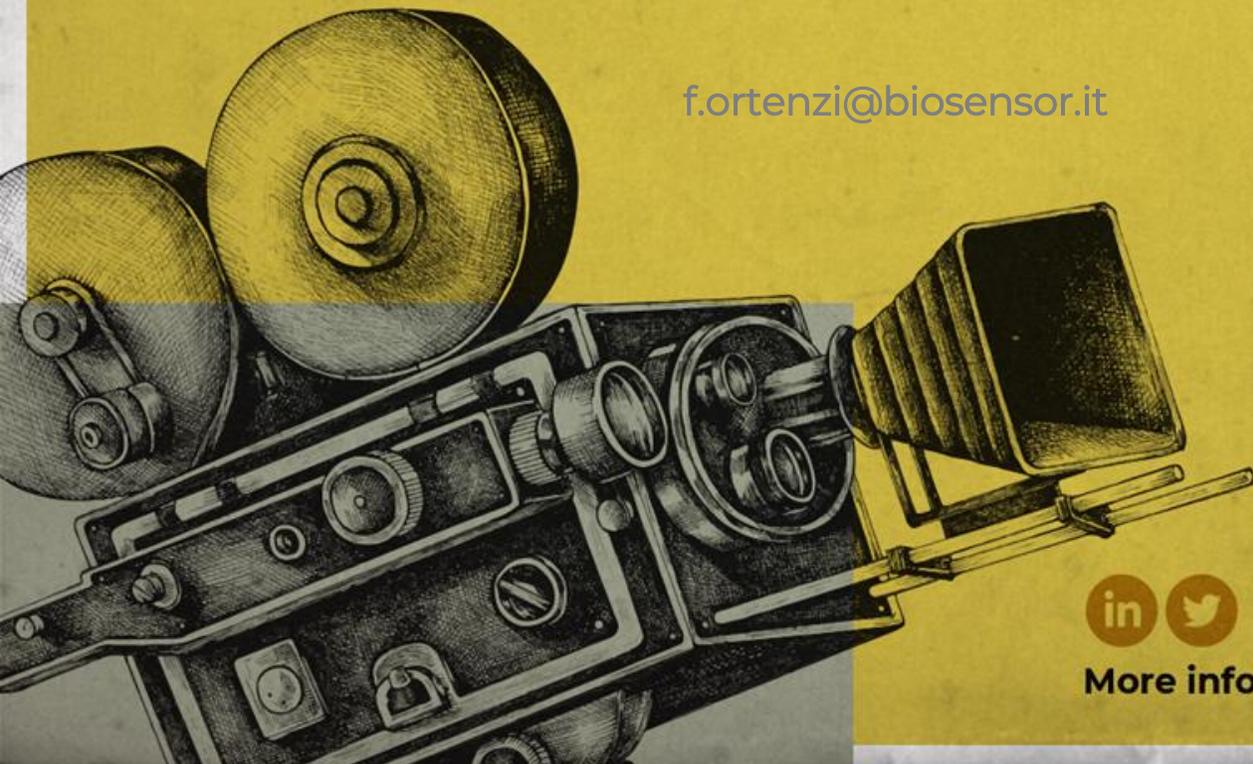
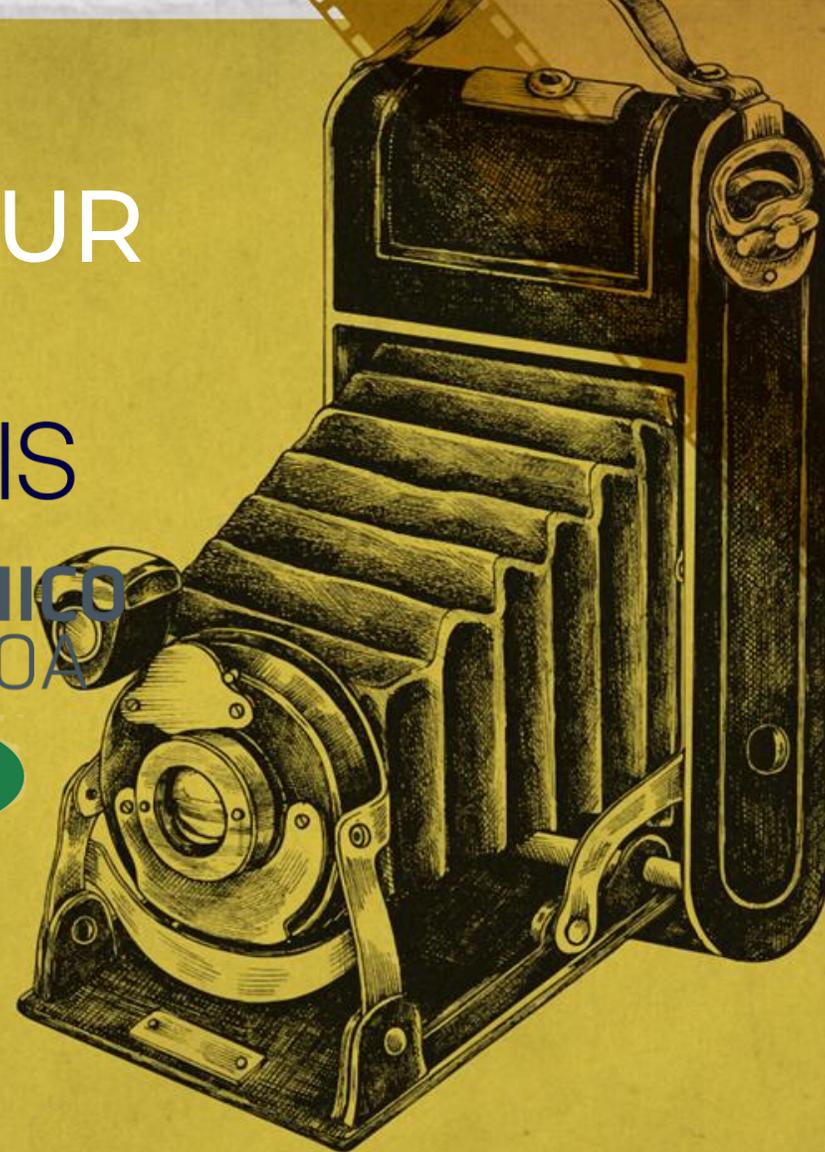
[ikakogiannos@iris-eng.com](mailto:ikakogiannos@iris-eng.com)



[abeer.mohtar@tecnico.ulisboa.pt](mailto:abeer.mohtar@tecnico.ulisboa.pt)



[f.ortenzi@biosensor.it](mailto:f.ortenzi@biosensor.it)



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



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