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Novità nella sensoristica per utilizzazioni in agricoltura

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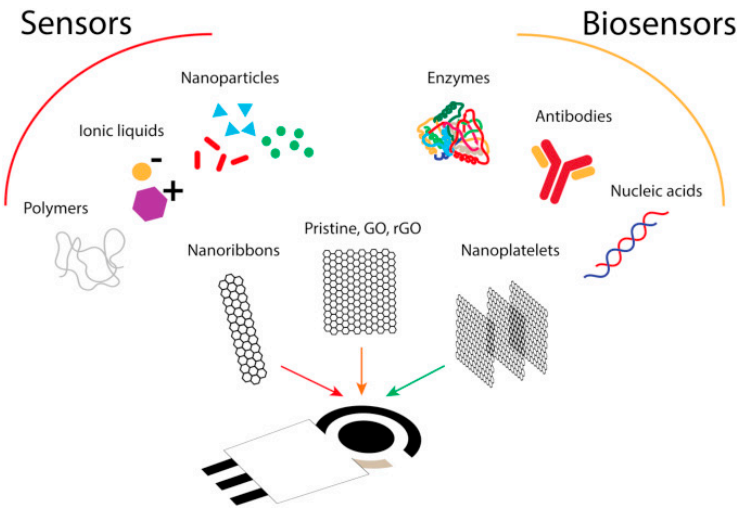
Workshop: Prospettive e sviluppo della sensoristica e della robotica in agricoltura
15/10/2021 ETE - EARTH TECHNOLOGIES EXPO (Firenze, Fortezza da Basso, 13-16 ottobre 2021, https://www.etexpo.it/)

SENSORE

di Fabiana Arduini, Laura Micheli, Daniela Romanazzo, Roberto Steindler - Enciclopedia Italiana - IX Appendice (2015)

SENSORE. – Sensori di grandezze chimiche. Classificazione e proprietà. Biosensori elettrochimici. Bibliografia. Sensori di grandezze fisiche. Sensori a semiconduttore. Sensori a fibre ottiche. Sensori IR. Sensori per mappe. Sensori di prossimità. Sensori di velocità. Bibliografia

Sensori di grandezze chimiche di *Fabiana Arduini, Laura Micheli, Daniela Romanazzo.* – I s. chimici sono dispositivi integrati in grado di identificare e/o quantificare, in un sistema in analisi, una o più specie chimiche (analiti). Possiedono caratteristiche analitiche quali l'elevata sensibilità, l'accuratezza e la rapidità di misura, nonché requisiti operativi quali le limitate dimensioni, la maneggevolezza e la stabilità nel tempo. Tali caratteristiche ne consentono la trasferibilità sul campo, per un tempestivo intervento di controllo, e l'uso per operatori non specializzati, fornendo un'importante e valida alternativa ai metodi analitici tradizionali. I s. chimici sono classificati in base al tipo di trasduzione di segnale impiegata.

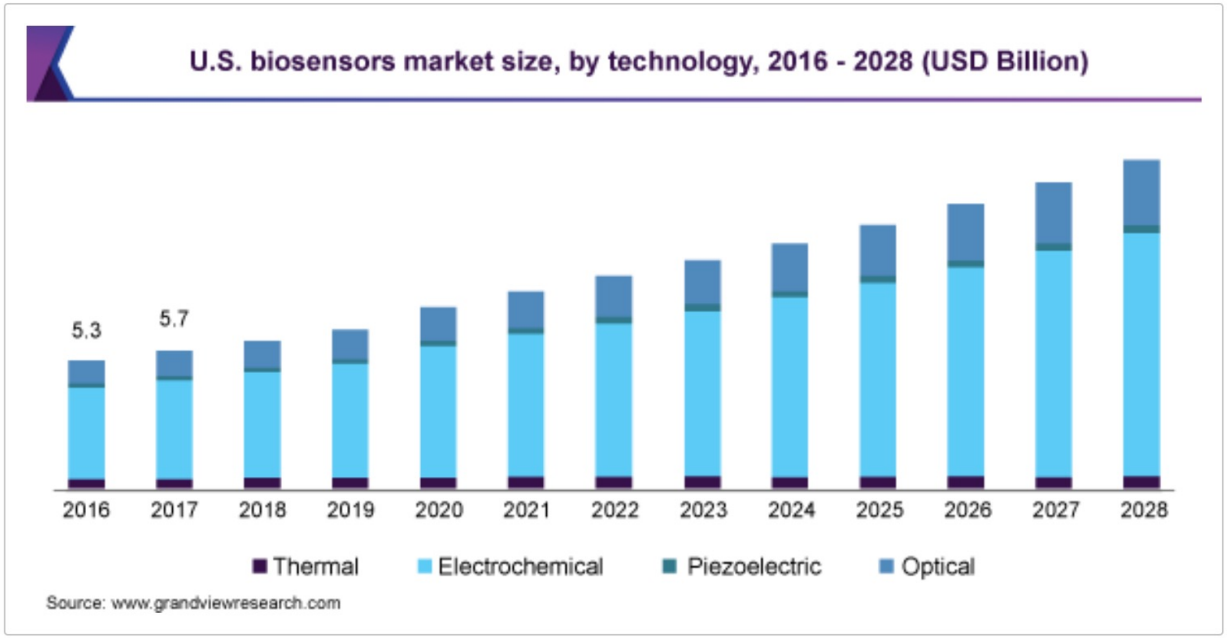


Biosensori elettrochimici. – Quando i s. chimici sono modificati con un biocomponente come un enzima, un anticorpo o una sequenza di DNA (*DeoxyriboNucleic Acid*), si definiscono *biosensori.* Un biosensore è un dispositivo analitico che incorpora un elemento di riconoscimento biologico (o di derivazione biologica) integrato o intimamente associato a un trasduttore di segnale chimico-fisico. Il segnale in uscita è conseguente alla reazione tra il biocomponente e l'analita e proporzionale alla concentrazione dell'analita stesso. I biocomponenti conferiscono ai s. chimici maggiori prestazioni in termini di specificità e sensibilità.

Quando il biocomponente è rappresentato da un enzima si parla di *biosensori enzimatici*, tra

Report Overview

The global biosensors market size was valued at USD 22.4 billion in 2020 and is expected to expand at a compound annual growth rate (CAGR) of 7.9% from 2021 to 2028. Biosensors, owing to their ability to assess health status, and disease onset and progression, are being used extensively in-home healthcare by patients, and hence, are expected to boost market growth over the forecast period. Furthermore, technological advancements, as well as various non-medical-based applications are expected to enhance the applicability of the market for biosensors, thus promoting its growth.

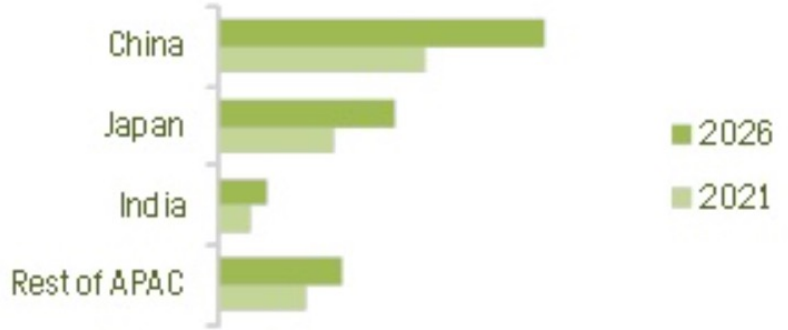


HIGHEST CAGR
(2021–2026)

China
Fastest-growing market
in APAC

BY APPLICATION, 2021 (USD BILLION)

BY COUNTRY, 2021 & 2026 (USD BILLION)



FACTORS DRIVING GROWTH OF MARKET IN APAC

Main companies worldwide commercialising biosensors

Abbott Laboratories	www.abbottdiagnostics.com	Diagnosis and treatment of diseases/illness
ABTECH Scientific Inc.	www.abtechsci.com	biomedical research
Bayer AG	www.bayerdiag.com	genetic diseases
Biacore International AB	www.biacore.com/lifesciences/in dex.html	Health care and medical products industry
Affymetrix	www.affymetrix.com/index.affx	biotherapeutic development/production, and proteomics
Cygnus, Inc.	www.cygn.com/homepage.html	Glucose monitoring
DiagnoSwiss	www.diagnoswiss.com	medical diagnostics, microbiology, food, warfare's, pharmaceutical research, proteomics, industrial control
Lifescan	www.lifescan.com	Glucose monitoring
Neogen Corporation	www.neogen.com	food and animal safety for environmental analysis
Panbio	www.alere.com	Tests for diagnosis of infectious disease
Roche Diagnostics AG	www.rochediagnostics.com	Biomedical, industrial, pharmaceutical, food analysis
Pelikan Technologies, Inc.	www.pelikantechnologies.com	Hand-held medical diagnostic
Applied Biophysics	www.biophysics.com	Biomedical research

FOOD QUALITY 6 SAFETY

Quality
- appearance, taste, nutritional value content, functional ingredient, freshness, flavour, texture and chemical
- presence of compounds enriching food: sugars, amino acid, alcohol, and additives as vitamins and minerals.

Safety
commercialise safe foods which do not represent a risk for the consumer, free from allergenic or toxic substances, pathogens, pesticides, fertilizers, heavy metals, organic compounds, toxins

SMART FARMING

Smart agriculture is based on multifarious approaches based on more energy-efficient and environmentally friendly cross-cutting technologies, including:
i) nanoformulation delivery systems to improve dispersion and wettability of nutrients/pesticides
ii) sensors for fertiliser/pesticide residue analysis of soil and crop, plant diseases, soil humidity
iii) remote sensing, yield mapping, and positioning systems for crop growth/disease control

SMART PACKAGING

- monitor the conditions of food
- sense freshness properties
- check the integrity of the packages during transport, storage and display in markets
- measure physical parameters (humidity, pH, temperature, light exposure),
- reveal gas mixtures (e.g. oxygen and carbon dioxide)
- detect pathogens and toxins
- control freshness (e.g. ethanol, lactic acid, acetic acid) and decomposition (e.g. putrescine, cadaverine)

PROCESS CONTROL

Biosensors for the measurement of a wide range of bioprocess substrates and products as glucose, ethanol, amino acids


Biosensor Trade in Agrifood Sector

10. Commercially Available (Bio)sensors in the Agrifood Sector 315

A. Antonacci, F. Arduini, D. Moscone, G. Palleschi, V. Scognamiglio

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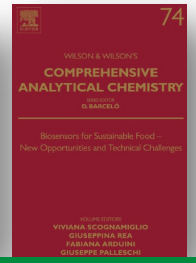


Food quality

Fuji Electric Co	Japan	Glucose
IBA GmbH	Germany	Sucrose, glucose, alcohol
GeneScan Europe AG/Scil Diagnostic GmbH	Germany	NutriChip, DNA detection with array technology
Oriental Electric Co.	Japan	Freshness meter: degradation products of ATP
Pegasus Biotechnology	Canada	Degradation products of ATP
Biosentec	France	Lactate
Analox Instruments	UK - USA	Ethanol, methanol, glucose, ethanol, lactate, glycerol
Sensolytics	Germany	Glucose, lactate, sucrose, ethanol, glutamate
BioFutura s.r.l.	Italy	Glucose, lactate, malate
Tectronik	Italy	Glucose, lactate, malate
Chemel AB	Sweden	Glucose, sucrose, lactate, ethanol, methanol
YSI Inc.	USA	Glucose, sucrose, lactate, lactose, ethanol, methanol, glutamate
Inventus BioTec	Germany	Ascorbic acid in juice, fruits, and vegetables

Senzytec instrument from Tectronik

measures ethanol, malic acid, lactic acid, glucose, and fructosein the agrifood sector with specific application in wine, oranges, and apples.

- reliable
- quick (3-6 minutes)
- low cost tests
- on-site analysis
- small sample volume (0.1 mL)

Analox Instruments (GM8, GM10, and GL6)

Provided glucose detection in beverages, based on electrochemical enzymatic assay

- very fast (20 seconds)
- good operational in complex matrices with high opacity or turbidity

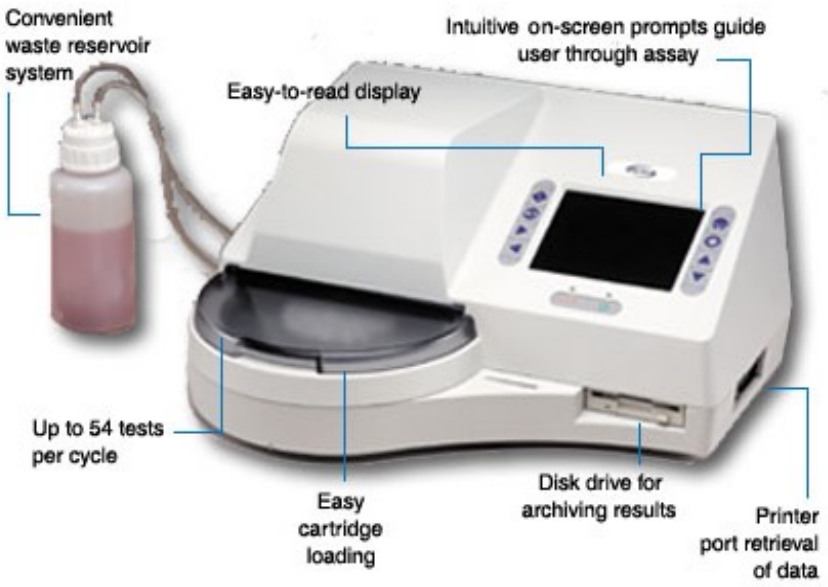
Food safety

Molecular Circuitry, Inc.	USA	E. coli O157, Salmonella, Listeria, and Campylobacter
Ambri Ltd	USA	Salmonella and Enterococcus
Biosensor Systems Design	USA	Microorganisms and toxic substances
Biosensores S.L.	Spain	On-line monitoring of the concentration of total microorganisms in water in 15 minutes
Motorola	Japan	Microorganisms and genetically modified organisms
Biacore GE	Worldwide	Folic acid, biotin, antibiotics in cereals, meat, milk, infant food, honey
Texas Instruments Inc.	USA	Sensors for gas and pH determination in food industry
Don Whitley Scientific Ltd.	UK	Sensors and components for microorganism detection
Integrated Genetics	USA	DNA probes for detection of microbial contamination (Salmonella)
Molecular Devices Corporation	USA	Sensors and components for microbial determination

Detex Pathogen Detection System from Molecular Circuitry Inc

The system is a patented electro-immunoassay biosensor to simultaneously test multiple pathogens: E. coli O157 (H7), Salmonella, Campylobacter and Listeria in food samples.

- high accuracy
- enhanced sensitivity
- improved specificity
- fast results on individual tests
- simultaneous testing for multiple pathogens



Process control

Universal Sensors	USA	Ethanol, methanol, glucose, sucrose, lactose, L-AAs, glutamine, ascorbic acid, oxalate
Yellow Springs Instruments	USA	Glucose, sucrose, lactose, L-lactate, galactose, L-glutamate, ethanol, H_2O_2, starch, glutamine, choline
BioFuture Srl	Italy	Glucose, fructose, malic acid, lactic acid
Chemel AB	Sweden	Glucose, saccharose, ethanol, methanol, lactose
Analox Instruments	UK, USA	Ethanol, methanol, glucose, lactate, glycerol
Nova Biomedical	USA	Glucose, L-lactate, L-glutamate, L-glutamine, alchol, sucrose, methanol, ammonia
Gwent Sensor Ltd.	UK	Sucrose, L-glutamate, alcohol
York Scientific technology	USA	Glucose, lactose, sucrose, galactose, lactate, ethanol/methanol, L-glutamate, L-amino acids
Biometra	Germany	Glucose, ethanol
Colora Messtechnik GmbH	Germany	Glucose, lactate, ethanol
NEC	Japan	Glucose, alcohol, L-lactate, glycerine
Provesta Corporation	USA	Glucose, lactate, lactose, alcohol

YSI 2900M Online Monitoring/Control System featuring the YSI 2960 Online Sampler

integrated system for bioprocesses analytes (e.g. glucose, lactate, glutamate, glutamine, glycerol, xylose, choline, hydrogen peroxide, sucrose, ethanol, methanol, lactose, and galactose)

- accurate
- results in less than 1 minute
- sterility

Gwent Sensor Ltd.

one-shot disposable biosensors for agrifood analysis:
i) ammonia
ii) lactate
iii) Glucose
iv) pyruvate

Smart packaging

Novas Insignia Technologies	UK	Gas - modified atmosphere
O2Sense™	Switzerland	Gas - amount of oxygen
FreshTag®	The Netherlands	Freshness - volatile amines
RipeSense®	New Zeland	Freshness - aromas released by the fruit as it ripens
3M MonitorMark®	USA	Time-Temperature - to estimate how long a product was above a threshold temperature (ranging between 15-31°C)
Timestrip Complete®	UK	Time-Temperature - to monitor high and low threshold temperature breaches outside selected ranges (2-8°C)
Fresh-Check®	USA	Time-Temperature - to irreversibly e fast monitor temperatures higher or lower than selected ones
CheckPoint®	Palestine	Time-Temperature - to monitor temperature ranges adapted to toxin formation of Clostridium botulinum
CoolVu Food®	Switzerland	Time-Temperature - to monitor the storage temperature
Innolabel Timestrip®	Belgium	Time-Temperature - to provide accurate shelf life guide for fresh fruit and vegetables
Chromatic Technologies, Inc.	USA	Thermochromic inks Reversible colour changes depending on temperature
Matsui International Company, Inc.	USA	Thermochromic inks Reversible colour changes depending on temperature

Oxysense

optical sensor for a non-invasive oxygen measurement for sealed packages: food, beverage, and pharmaceutical industries.

- Sensitive
- rapid (5 sec)
- not-destructive measurements

Food Sentinel System™ (SIRA Technologies, California, USA)

immuno-biosensor system patented on 2000 (EP 1018013 A1) occurring in part of a barcode, able to continuously detect contaminating bacteria.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Biosensors and Bioelectronics 172 (2021) 112750

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Biosensors and Bioelectronics

journal homepage: http://www.elsevier.com/locate/bios

Wearable electrochemical biosensors in North America

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ARTICLE INFO

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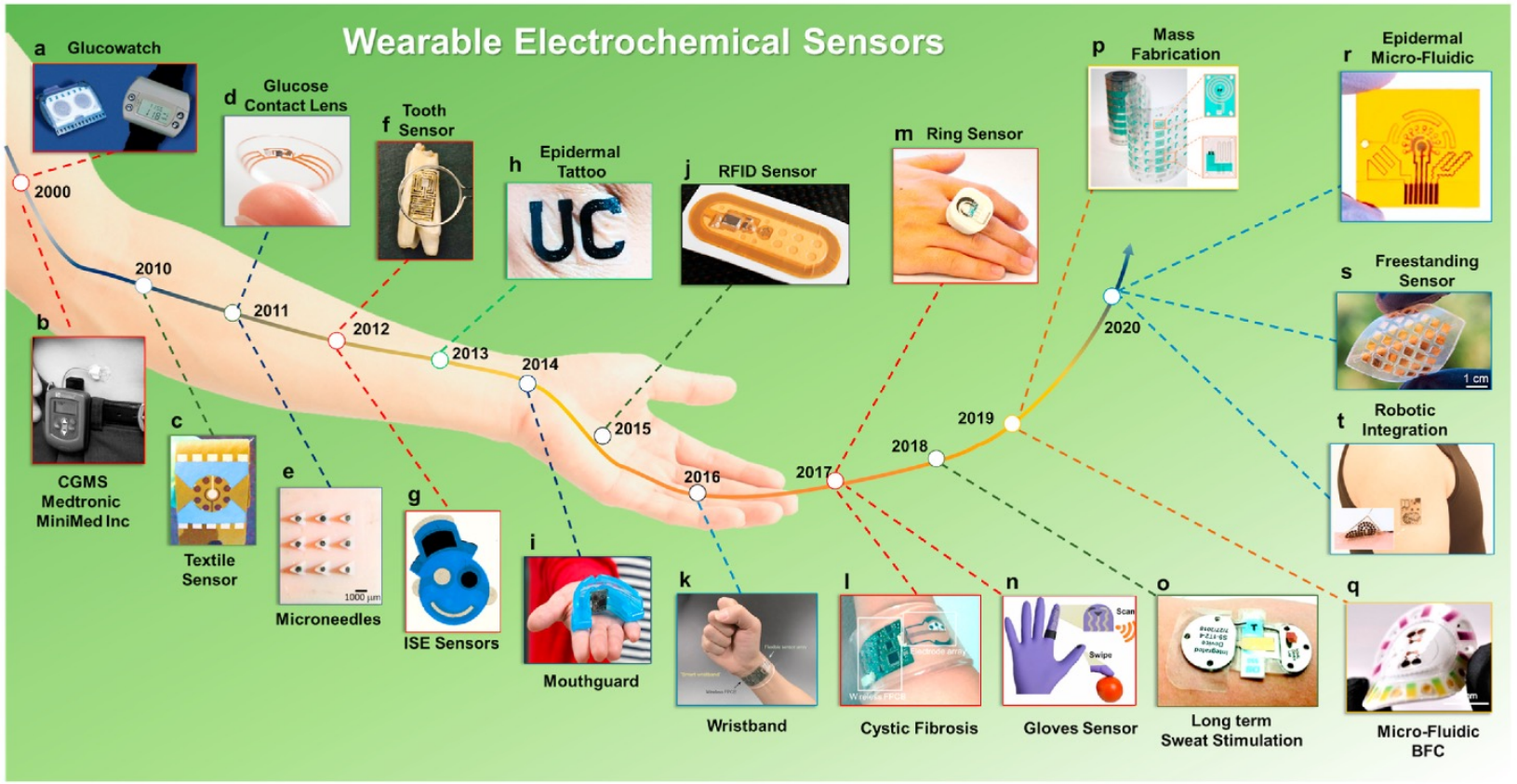
Flexible electronics
Electrochemistry
Personalized medicine
COVID-19
Telemedicine

ABSTRACT

Tremendous research and commercialization efforts around the world are focused on developing novel wearable electrochemical biosensors that can noninvasively and continuously screen for biochemical markers in body fluids for the prognosis, diagnosis and management of diseases, as well as the monitoring of fitness. Researchers in North America are leading the development of innovative wearable platforms that can comfortably comply to the human body and efficiently sample fluids such as sweat, interstitial fluids, tear and saliva for the electrochemical detection of biomarkers through various sensing approaches such as potentiometric ion selective electrodes and amperometric enzymatic sensors. We start this review with a historical timeline overviewing the major milestones in the development of wearable electrochemical sensors by North American institutions. We then describe how such research efforts have led to pioneering developments and are driving the advancement and commercialization of wearable electrochemical sensors: from minimally invasive continuous glucose monitors for chronic disease management to non-invasive sweat electrolyte sensors for dehydration monitoring in fitness applications. While many countries across the globe have contributed significantly to this rapidly emerging field, their contributions are beyond the scope of this review. Furthermore, we share our perspective on the promising future of wearable electrochemical sensors in applications spanning from remote and personalized healthcare to wellness.


Wearable Electrochemical Sensors
a Glucowatch
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CGMS
Medtronic
MiniMed Inc
c
Textile
Sensor
d Glucose
Contact Lens
e
Microneedles
f Tooth
Sensor
g
ISE Sensors
h Epidermal
Tattoo
UC
i
Mouthguard
j RFID Sensor
k
Wristband
l
Cystic Fibrosis
m Ring Sensor
n
Gloves Sensor
o
Long term
Sweat Stimulation
p Mass
Fabrication
q
Micro-Fluidic
BFC
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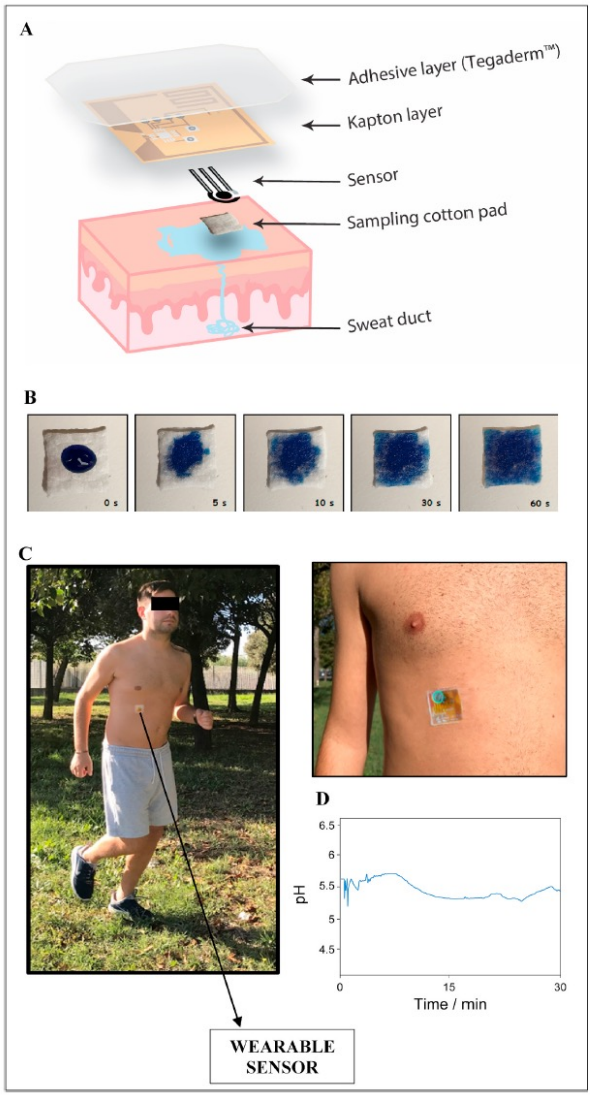

Talanta 222 (2021) 121502

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Talanta

journal homepage: www.elsevier.com/locate/talanta

Medium-distance affordable, flexible and wireless epidermal sensor for pH monitoring in sweat

Vincenzo Mazzaracchio [a], Luca Fiore [a], Simone Nappi [b], Gaetano Marrocco [b,c,**], Fabiana Arduini [a,d,*]

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[b] Department of Civil Engineering and Informatics, University of Rome Tor Vergata, Via del Politecnico,1, 00133, Rome, Italy
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nature medicine

LETTERS

https://doi.org/10.1038/s41591-020-1123-x

Check for updates

Wearable sensor data and self-reported symptoms for COVID-19 detection

Giorgio Quer[1,3]✉, Jennifer M. Radin[1,3], Matteo Gadaleta[1,3], Katie Baca-Motes[1], Lauren Ariniello[1], Edward Ramos[1,2], Vik Kheterpal[2], Eric J. Topol[1] and Steven R. Steinhubl[1]

Traditional screening for COVID-19 typically includes survey questions about symptoms and travel history, as well as temperature measurements. Here, we explore whether personal sensor data collected over time may help identify subtle changes indicating an infection, such as in patients with COVID-19. We have developed a smartphone app that collects smartwatch and activity tracker data, as well as self-reported symptoms and diagnostic testing results, from individuals in the United States, and have assessed whether symptom and sensor data can differentiate COVID-19 positive versus negative cases in symptomatic individuals. We enrolled 30,529 participants between 25 March and 7 June 2020, of whom 3,811 reported symptoms. Of these symptomatic individuals, 54 reported testing positive and 279 negative for COVID-19. We found that a combination of symptom and sensor data resulted in an area under the curve (AUC) of 0.80 (interquartile range (IQR): 0.73–0.86) for discriminating between symptomatic individuals who were positive or negative for COVID-19, a performance that is significantly better ($P < 0.01$) than a model[1] that considers symptoms alone (AUC = 0.71; IQR: 0.63–0.79). Such continuous, passively captured data may be complementary to virus testing, which is generally a one-off or infrequent

significantly improve real-time predictions for influenza-like illness[8]. Consequently, we created a prospective app-based research platform, called DETECT (Digital Engagement and Tracking for Early Control and Treatment), where individuals can share their sensor data, self-reported symptoms, diagnoses and electronic health record data with the aim of improving our ability to identify and track individual- and population-level viral illnesses, including COVID-19.

A previously reported study that captured symptom data in over 18,000 SARS-CoV-2-tested individuals via a smartphone-based app found that symptoms were able to help distinguish between individuals with and without COVID-19[1]. The aim of this study is to investigate if the addition of individual changes in sensor data to symptom data can be used to improve our ability to identify COVID-19-positive versus COVID-19-negative cases among participants who self-reported symptoms.

Between 25 March and 7 June 2020, our research study enrolled 30,529 individuals, with representation from every state in the United States. Among the consented individuals, 62.0% are female and 12.8% are 65 or more years old. Of the participants, 78.4% connected their Fitbit devices to the study app, 31.2% connected the data from the Apple HealthKit, while 8.1% connected data from Google Fit (note that an individual can connect to multiple plat-

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PERSPECTIVE

ADVANCED FUNCTIONAL MATERIALS
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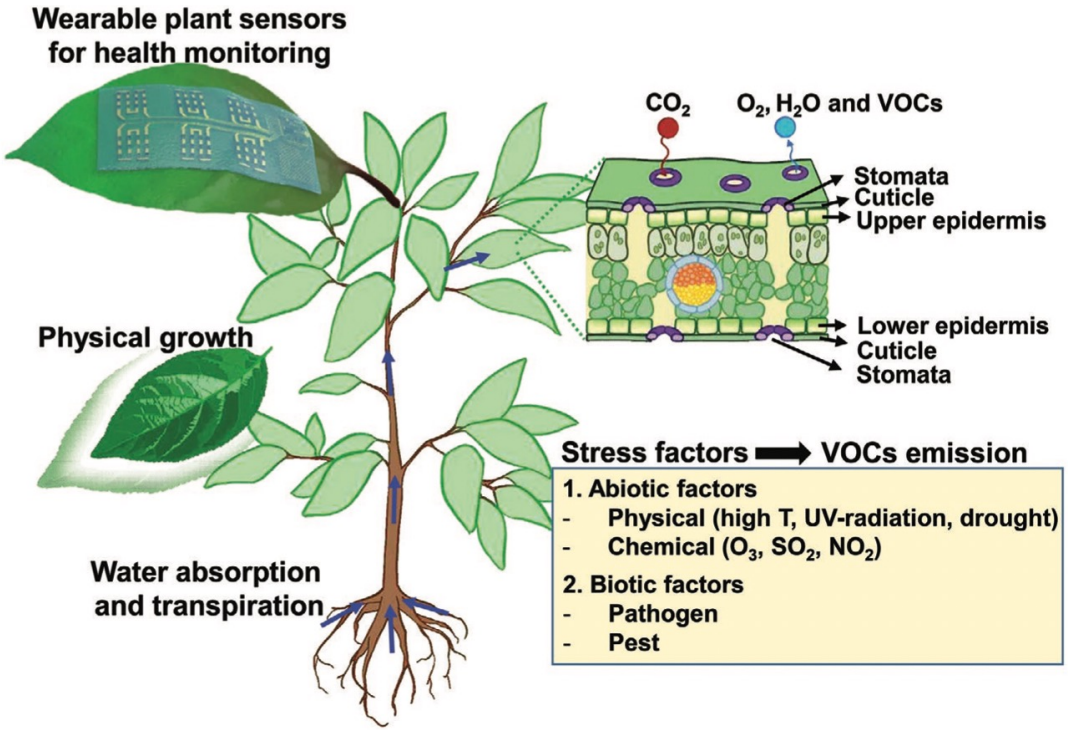
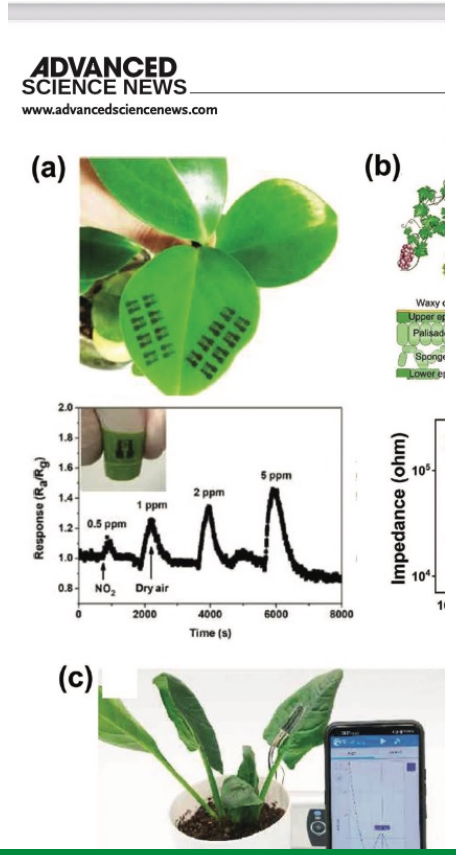
Emerging Wearable Sensors for Plant Health Monitoring

Giwon Lee, Qingshan Wei, and Yong Zhu**





Biosensors and Bioelectronics 126 (2019) 346–354

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Biosensors and Bioelectronics

journal homepage: www.elsevier.com/locate/bios

Origami multiple paper-based electrochemical biosensors for pesticide detection

F. Arduini[a,*], S. Cinti[a], V. Caratelli[a], L. Amendola[b], G. Palleschi[a], D. Moscone[a]

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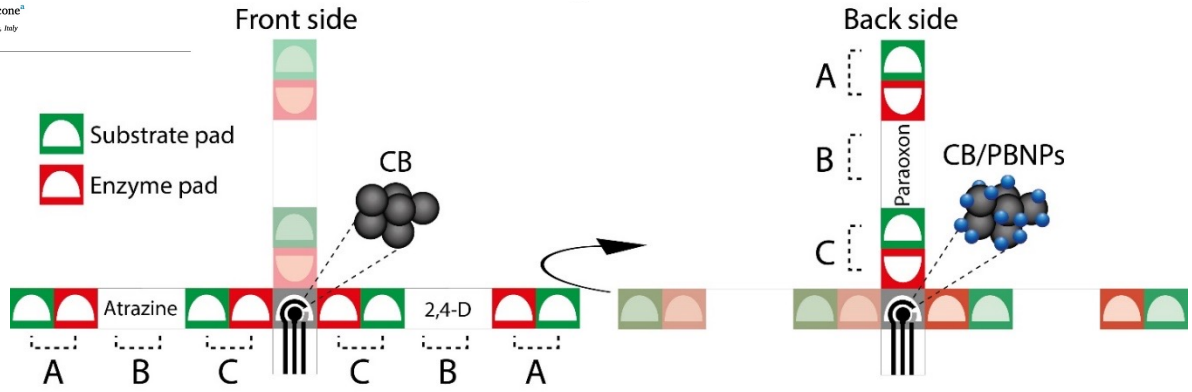
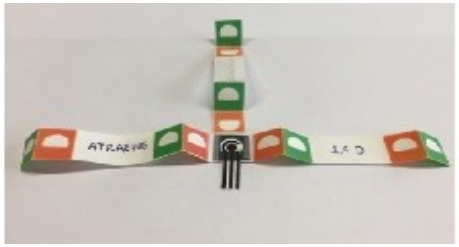
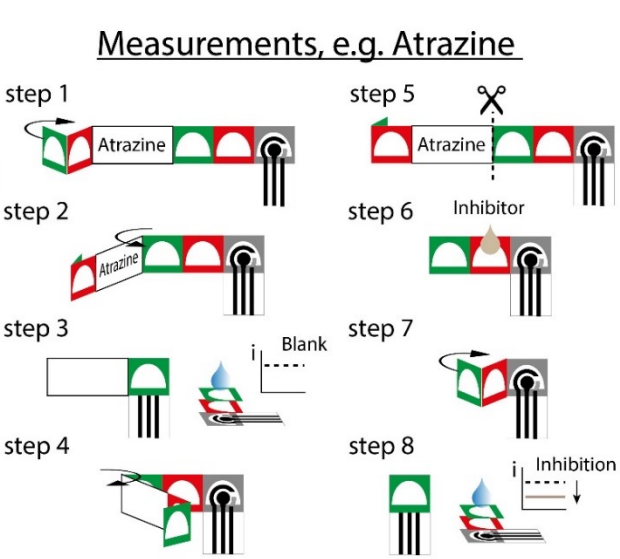
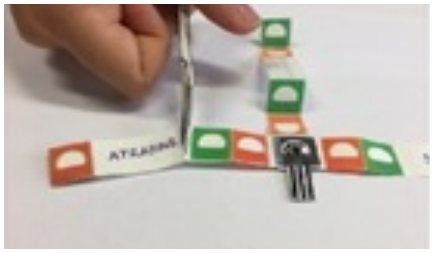
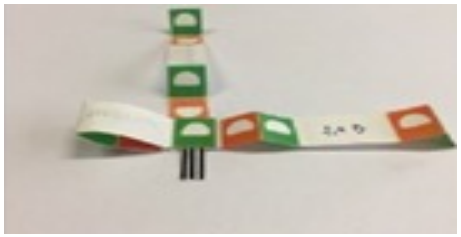
[b] ArpaLazio, Via Giuseppe Saredo 52, 00173 Rome, Italy

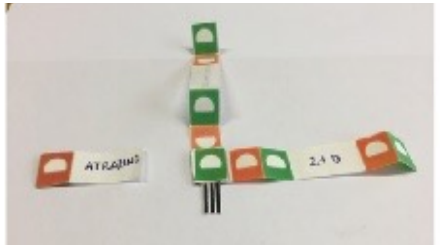


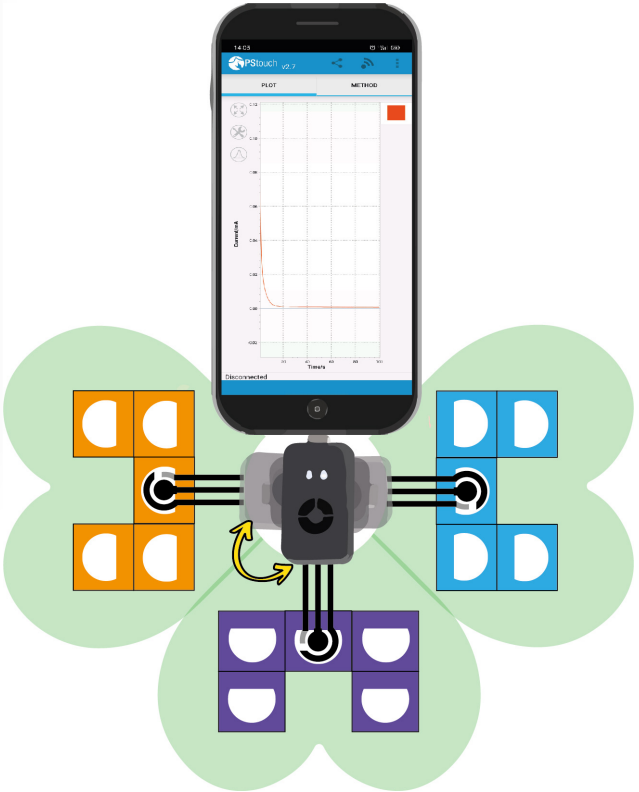


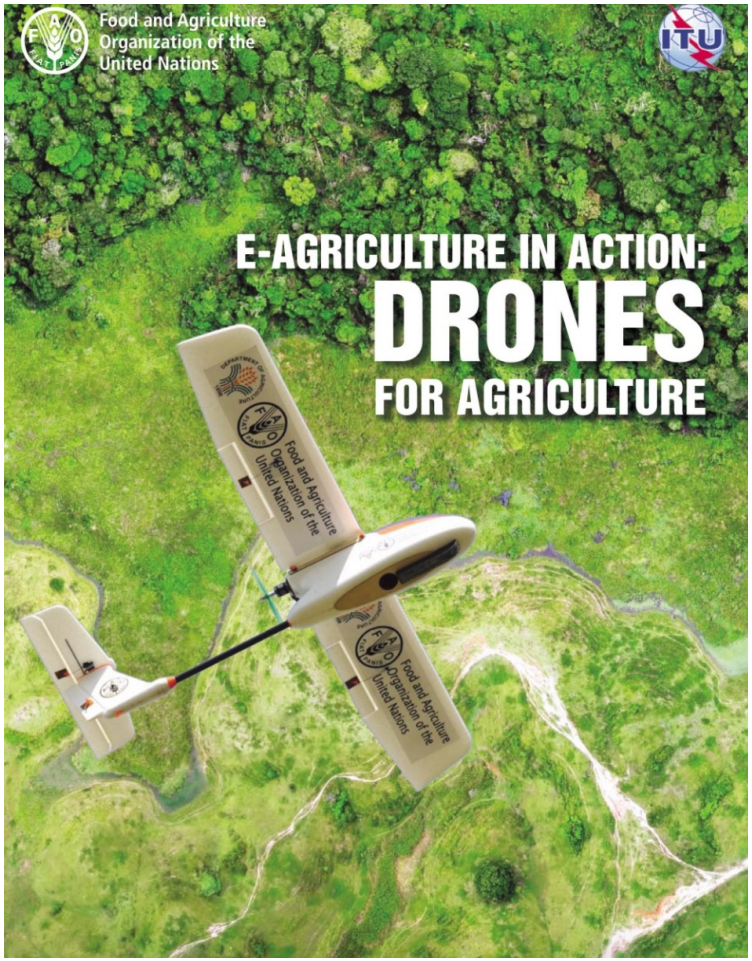








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Thank you

for the kind attention!