Team Results Document

TUcanSense

Technical University Darmstadt

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SensUs

List of abbreviations

Abbreviation	*Meaning*
AKI	Acute Kidney Injury
CD	Cartridge and Device
CE	Counter Electrode
CV	Cyclic Voltammetry
DMF	Dimethylformamide
GFR	Glomerular filtration rate
GUI	Graphical user interface
HEPES	4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid
ISF	Interstitial skin fluid
MB	Methylene blue
MC	Microfluidic chip
MCH	6-mercaptohexanol
MR	Molecular recognition
NHS	N-Hydroxysuccinimide
PT	Physical Transduction
RE	Reference electrode
RI	Reader Instrument
RSD	Relative standard deviation
SD	Standard deviation
SPE	Screen printed electrode
TCEP	Tris(2-carboxyethyl)phosphine
WE	Working electrode

1. Abstract: Summary for the SensUs website

For the SensUs Student Competition 2025, our team TUcanSense from Technical University of Darmstadt, Germany, developed an innovative concept and prototype for a continuous biosensor to monitor creatinine levels in interstitial skin fluid (ISF), which is an important marker of kidney function. Our system integrates aptamers with custom-made screen-printed electrodes and electrochemical readout techniques, offering a reliable, robust, and cost-effective platform. Designed for continuous use, the sensor is reversible: the aptamers can be regenerated through heat, allowing repeated measurements without compromising performance.

Although the current prototype is lab-based, the overall concept is built for future wearable integration, enabling non-invasive, real-time kidney health monitoring. While related research exists, no complete or commercial solution is currently available, positioning our approach as a novel, impactful step forward.

Through interviews with patients and kidney health professionals, our team gained valuable insights that shaped the device's design, prioritizing user comfort, ease of use, and accessibility. Our target users are populations in rural and underserved areas, where access to specialist care is limited, and preventive care is crucial.

Beyond a sensor, we developed the Kidney Health System. The comprehensive solution for preventive care and continuous kidney health monitoring empowers individuals to detect early signs of dysfunction and manage their health proactively.

2. AP award: Biosensor developed for the Eindhoven Testing Event

2.1. Molecular recognition (MR)

The creatinine is detected with a DNA-based aptamer and is modified with a 5'-thiol group (via a C6 linker) and a 3'-terminal amine group (Ganguly et al., 2024). Before immobilization, the thiol protection group is removed using Tris (2-carboxyethyl)phosphine (TCEP) (Tapio et al., 2021). After a 10-minute incubation, aptamer (100 µM) is immobilized onto gold-plated Screen-Printed Electrodes (SPE) via thiol–gold self-assembly. To reduce non-specific binding, the electrode surface is blocked using 10 µM 6-Mercaptohexanol (MCH)(Szymczyk et al., 2022). Methylene blue (MB) is then covalently attached to the 3'- amine-modified aptamer using the MB and N-Hydroxysuccinimide (NHS) ester in a HEPES and DMF buffer (Ferapontova & Gothelf, 2009). All solutions are freshly prepared and steps are done under light-protected conditions with MilliQ water. The electrochemical mechanism is shown in Figure 1. Once immobilized, the MB-labeled aptamer remains inactive (step 1). Upon exposure to an ISF sample containing creatinine (step 2), the aptamer undergoes a conformational change (step 3), reducing the distance between MB and the SPE and therefore allowing a better electron transfer. The current created by the electron transfer of the redox reaction can be measured using cyclic voltammetry (CV) and linked to the creatinine concentration. To regenerate the aptamer for reuse, the electrode is heated to 50 °C ±7 °C for 60 s, causing the release creatinine (step 4).

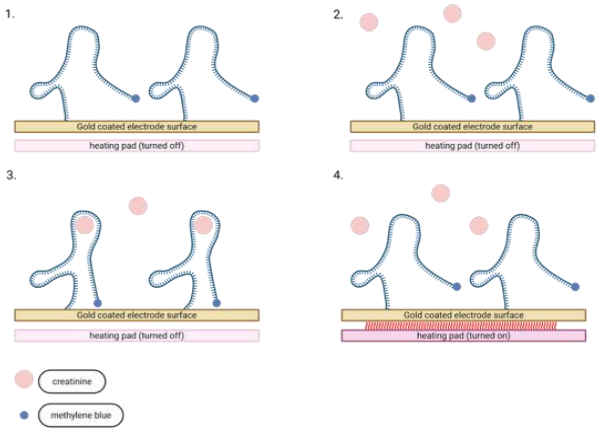

Figure 1: Simplified illustration of our aptamer creatinine biosensor. Figure created with BioRender.com.

2.2. Physical transduction (PT)

As electrochemical transduction method, cyclic voltammetry is chosen for its precision and simplicity (Gonzalez-Gallardo et al., 2022). A triangular voltage is applied and the current change caused by a redox reaction between an immobilized aptamer and the analyte is measured (Fahmy Taha et al., 2020). The sensor includes a Working electrode (WE), a Reference electrode (RE) and a Counter Electrode (CE) (Figure 2). The aptamer is immobilized on the WE and binds to creatinine, while the RE stabilizes voltage and the CE closes the circuit (Bhardwaj, 2015). The electrodes used in this system are custom-made for their sensitivity, low

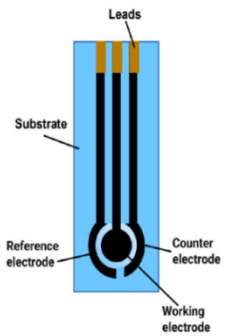

Figure 2: SPE from Pandey et al., 2019.

sample volume, and cost-effectiveness (Jadhav et al., 2024). Silver/silver chloride ink is used for the RE, and silver ink for the other electrodes to improve performance and longevity. After the printing process, WE and CE were covered with chrome and gold by vaporization deposition.

2.3. Cartridge technology (CD)

The fluidic system is composed of the Microfluidic chip (MC) combined with manual pumping to deliver ISF samples to the electrode (Figure 3). The MC contains a straight microchannel to avoid stagnation and cross-contamination between consecutive samples, and a detection chamber that aligns precisely with the electrode for ISF delivery. A double-sided adhesive tape seals the chip-electrode interface. Between tests, the chamber is cleared with air for aptamer's thermal regeneration to occur (Fahmy Taha et al., 2020). Each cycle takes 5 minutes to complete and allows the efficient testing of 24 ISF samples in 2 hours.

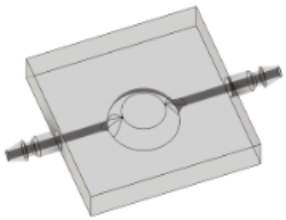

Figure 3: Microfluidic chip.

2.4. Reader instrument and user interaction (RI)

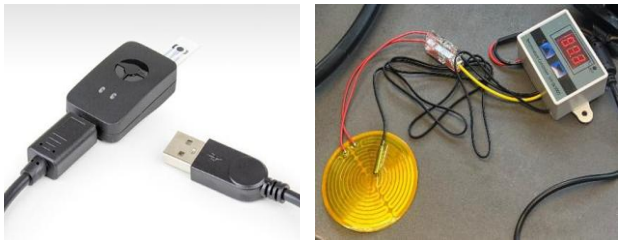

Figure 4: Sensit Smart potentiostat and heating device.

The hardware includes a compact potentiostat *Sensit Smart* (PalmSens, 2025) and a 13 W heating pad (Ø70 mm) with a digital controller (Figure 4). The pad maintains a temperature of 50 °C for aptamer regeneration.

The Graphical User Interface (GUI) features five organized tabs, Data Visualization, and Connection Status provide full hardware control, creatinine result display and device connectivity feedback (Figure 5). Tabs for Patient Info, Health Journal, and Health Trends support non-expert users. They enable Glomerular Filtration Rate (GFR) calculation, daily hydration tracking and long-term health trend visualization. User-friendly design ensures intuitive use, whether by professionals or patients.

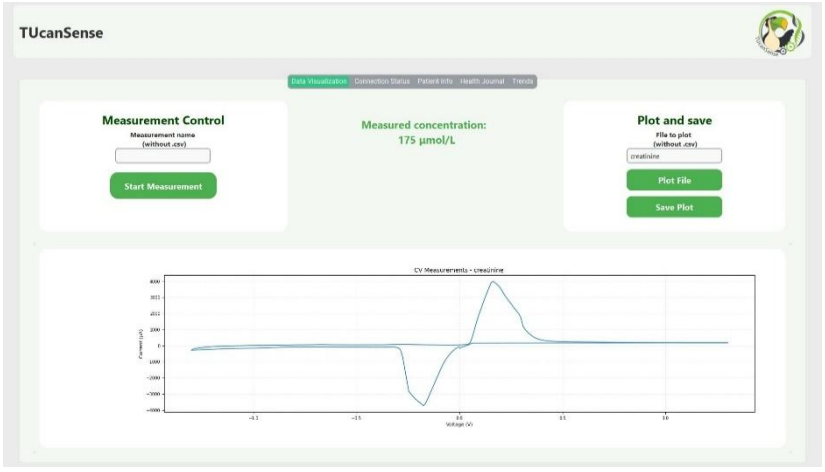

Figure 5: Self-made GUI.

3. IN award: Biosensor innovation

3.1. Wearable sensor

3.1.1. Technological novelty of wearable sensor

Although anti-creatinine aptamer-based recognition combined with CV is well documented in the literature, no device currently implements this approach in a fully integrated and reliable manner to enable reversible and continuous detection. The use of MB as a redox-active label offers an innovative method for signal amplification. Gold-plated SPEs are an established platform for electrochemical biosensing: our custom-made electrodes are screen-printed with silver inks and plated with vapor-deposited chrome and gold manufactured in-house; they demonstrate superior robustness, reliability, and reproducibility compared to commercial alternatives. The decision to perform electrochemical measurements directly in ISF, more specifically in combination with our aptamer-based molecular recognition unit, represents a novel approach: in contrast to optical methods, the electrochemical design offers remarkable miniaturization potential due to SPEs, which provide an ideal platform for compact sensor integration. The system operates with low power consumption and can be implemented in a wearable sensor unit. It also has the advantage of being connectable to an app-based reader software for real-time monitoring.

To our knowledge, no existing wearable electrochemical device enables continuous creatinine monitoring and possible measurement of related biomarkers, such as electrolytes or estimated GFR, directly in ISF. This underlines the uniqueness and potential impact of our platform.

3.1.2. Technical feasibility of wearable sensor

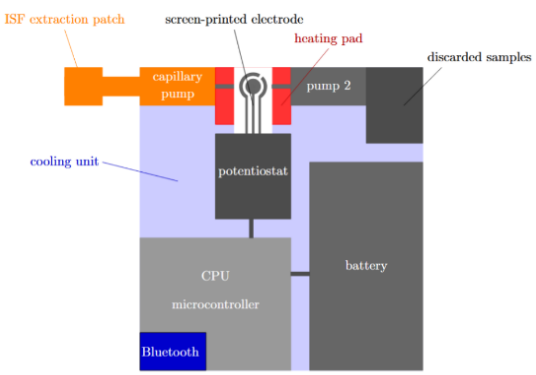

Figure 6: Biosensor sketch.

The proposed design of our wearable sensor comprises an ISF extraction patch, an SPE, a microfluidic pump, a heating pad, a battery, a potentiostat, a microcontroller, a CPU unit, and two cooling units. A design sketch is shown in Figure 6.

During a measurement, the sequence of the steps required is controlled by the CPU unit via the microcontroller. The battery enables the long-term use of the device. In addition, patients can exchange the SPEs in case they deteriorate. For the read-out of the creatinine concentration, a Bluetooth module sends

the data to a terminal such as a smartphone or a laptop. To provide continuous and non-invasive extraction of ISF, we propose an extraction patch, which allows the extraction of ISF at a rate of 0.85 µL/min (Takeuchi et al., 2019). The microfluidic system consists of an array of micro-needles through which the extraction is driven by a capillary pump. In addition, the patch is manufactured from polydimethylsiloxane, which makes it biocompatible (Victor et al., 2019). For the integration into our biosensor design, we modify the proposed design by moving the capillary pump in front of the assay chamber. For the implementation, clarification is required on whether this change impairs the function of the patch. Furthermore, the possibility to increase the extraction rate by applying more micro-needles needs to be investigated. Previously, we established that we immobilize aptamers onto the electrode surface. In order to prevent sample overlay, we recover the aptamers by heating them up to a temperature of ~50 °C. Since our device is supposed to be wearable, it must be quite small, which causes two challenges. First, we need to prevent the patient from getting burned during the heating step. Second, electronic components are more likely to fail due to overheating. We assess thermal tolerances of the adjacent electronic components, specifically the microfluidic pump and the potentiostat. According to the datasheet, the pump can operate safely at temperatures up to 70 °C. To ensure reliable CV measurements and economic manufacturing, we aim to develop a self-engineered PCB potentiostat. In doing so, we will use the *Sensit smart* potentiostat and the integrated *EmStat Pico* device from PalmSens as a benchmark for temperature values. The *Sensit smart* has a specified maximum ambient operating temperature of 40 °C. However, its internal components *EmStat Pico* are rated to function at up to 85 °C and after some calculation, we notice that the temperature received by the potentiostat should be around 37,7 °C (Appendix A). An additional solution is heating sinks: they are widely used in electronics as passive cooling devices that require no electrical power. They exist in various geometries and transfer heat from devices to fluids or air (Silva-Romero et al., 2024). Without active cooling, heat sinks typically support a thermal load range of 5 to 50 W, depending on their size, material, and design (Lee, 1995). In our application, the heating pad operates at approximately 13 W, which is within a heat sink's passive cooling capacity. Whether this is sufficient to mitigate, the temperature challenge needs further investigation. additional solution is heating sinks: they are widely used in electronics as passive cooling devices that require no electrical power.

Once creatinine can be reliably quantified via CV under medical conditions, we plan to replace SPEs with needle-based electrodes for direct insertion into the interstitial tissue, avoiding manual ISF extraction. Sensor data will be sent via BLE (Bluetooth low energy) to our GUI comparable to those used in glucose monitors.

3.2. Reliability of sensor output

3.2.1. Technological novelty of reliability concept

Our biosensor uses aptamer-based recognition for selective and reusable creatinine detection. Unlike commercial SPEs, our in-house gold-plated SPEs remain functional over multiple uses, reducing cost and waste. While gradual corrosion may occur, this can be addressed with improved surface platings in future iterations.

Two key innovations support the sensor's reliability: our SPEs and a data translation algorithm (Appendix B). Due to some variability in the printing process, each electrode undergoes a two-stage validation: a dry-state zero-line test confirms surface integrity, followed by a control measurement using blank ISF to ensure proper aptamer-related redox peaks. Only electrodes passing both tests are used for creatinine detection. To improve stability and accuracy, an internal Ag/AgCl RE and a carry-over correction algorithm to address residual analyte from prior tests, are added. Future development includes automated performance checks using known reference samples. If signal drift is detected beyond thresholds, the system will prompt users to replace the electrode.

Together, this design features reusable SPEs, strict pre-use validation, carry-over correction, and ensures reliable and continuous creatinine monitoring.

3.2.2. Technical feasibility of reliability concept

Our wearable system uses gold-plated SPEs functionalized with creatinine-specific aptamers. A drop of ISF is pipetted via the MC onto the electrode. The potentiostat receives signals from the electrode and performs a CV measurement. The measured current varies with aptamer-creatinine binding and yields the concentration. After a measurement, the electrode is heated to about 50 °C to break the aptamer-analyte complex and free the analyte.

The most critical components of our system are:

- the aptamer coating, whose surface density and uniform distribution directly governs both sensitivity and selectivity;
- the quality of the gold SPE, since variations in layer thickness or surface roughness translate into changes in baseline noise;
- The potentiostat electronics, which must deliver exceptionally stable potential control and ultra–low-noise current measurements in the nanoampere range.

Equally important is the thermal regeneration process: the chosen 50 °C must be sufficient to dissociate the aptamer–analyte complexes without compromising the secondary structure of the aptamers or damaging the gold surface of the SPE.

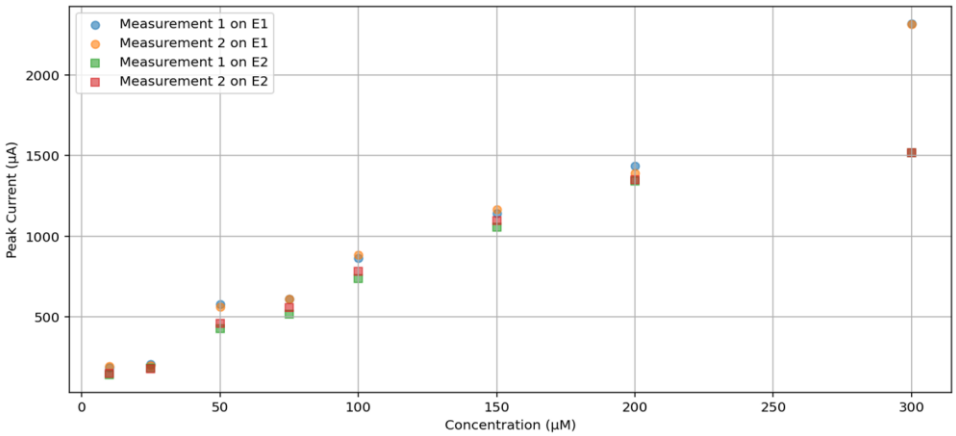

Figure 7: Current vs Concentration - Electrodes E1 and E2

To evaluate the reliability of our sensor measurements, we designed an experimental protocol using standard creatinine solutions with concentrations ranging from 10 µM to 300 µM. At each concentration level, two measurements are carried out on two separate electrodes (E1 and E2), enabling the assessment of both intra-electrode and inter-electrode reproducibility. The resulting peak currents are plotted in Figure 7, showing good consistency between repeated measurements and comparable responses between the two electrodes across most concentrations. Inter-electrode divergence became more apparent at concentrations exceeding 200 µM, while agreement is maintained within the 10–200 µM range. To quantitatively evaluate measurement repeatability, we calculated the standard deviation and Relative Standard Deviation (RSD) for each concentration (Appendix C).

Expressed as a percentage, the RSD reflects the relative variability of the signal. Low RSD values indicate good precision and repeatability. As shown in Table 1 (Appendix D), intra-electrode RSD values are consistently below 5.5 % across the entire concentration range, demonstrating robust sensor repeatability. The variability observed may be attributed to nonlinear effects such as electrode surface saturation or limitations in mass transport kinetics. To evaluate the consistency between different electrodes, we computed the inter-electrode variability using the relative difference in mean current between E1 and E2 (Appendix E). This metric captures the degree of divergence between electrodes at each concentration. The results, shown in Table 2 (Appendix C), reveal that inter-electrode variability remains low within the 10–200 µM range. At 300 µM, a marked increase in variability is observed, consistent with the intra-electrode trends and suggesting saturation-related effects.

3.3. Original contributions

The team: The TUcanSense Team 2025 biosensor concept is based on the 2024 team's concept of using aptamers as biosensing elements. Although the previous team faced challenges in verifying the immobilization of the aptamers, we recognized their advantages. Based on a comprehensive literature review on biosensing we identified their cost-effectiveness, favorable biochemical properties and reversible binding. Initially, we also investigated enzymatic recognition but terminated the approach because of inconsistent electrode signals, poor enzyme activity and high material costs. We improved the aptamer-based approach by optimizing immobilization and utilizing methylene blue. Qualitative and quantitative measurements were conducted via cyclic voltammetry due to reliability and simplicity. Our in-house manufactured screen-printed gold electrodes outperformed commercial ones in robustness and continuous-use suitability. Key innovations of our biosensor include a novel data processing algorithm and a microfluidic design, both independently developed and tested by our team. Additionally, we created a Python-based user interface for real-time creatinine monitoring. Expert interviews with industry and academic professionals provided valuable input throughout development. All scientific validation of our electrochemical aptamer-based biosensor was conducted by our team independently.

Supervisor: The TUcanSense 2025 team successfully developed a continuous electrochemical aptamer-based biosensor. Building upon the 2024 team's initial concept, the current team made substantial improvements that go far beyond refinement. After a comprehensive literature review, the team conducted comparative testing of enzymatic vs. aptamer-based recognition, ultimately discarding the enzymatic approach due to signal instability and material cost. This decision led to improvements in the aptamer immobilization as well as the integration of methylene blue as a redox reporter to enable clear electrochemical signals. The team developed and fabricated their own screen-printed electrodes, which outperformed commercial versions in terms of stability and continuous use. They also designed a custom microfluidic system tailored to continuous measuring. To facilitate the readout, the students developed a novel signal processing algorithm and user interface for real-time monitoring of creatinine concentrations. Overall, the team demonstrated technical competence, creativity and independence. Their biosensor represents a clear innovation in both design and functionality, and showcases a thoughtful, research-driven development process.

J. Hoffmann, Team Captain | L. Carmona, Team Captain | Prof. Blaeser, Supervisor

4. TP award: Translation potential

4.1. Customer interviews

We conducted a series of interviews with key stakeholders to explore and validate potential use cases for a continuous creatinine biosensor to monitor kidney function. To gain diverse insights, we engaged with patients and medical professionals. Three kidney patients and two specialized physicians in Germany were interviewed using a questionnaire based on the "Mom Test" method (Fitzpatrick, 2013)(Appendix G). Their conditions included membranous glomerulonephritis, steroid-resistant nephrotic syndrome, and chronic kidney disease. Patients emphasized the mental burden of kidney disease, including stress and uncertainty. One noted that real-time feedback would have eased anxiety, a transplant patient highlighted the benefit of continuous monitoring, and another wanted to check creatinine between appointments for peace of mind. Routine checkups are time-consuming, though patients saw limited need for continuous home sensors during stable phases.

To complement the patient's perspective, we interviewed Dr. Hansen, a nephrologist at the Clementine Kidney Centre and Dr. Schumacher, a laboratory physician in Germany. Standard analytic machines measure creatinine reliably and cost-effectively in a few minutes. Dr. Schumacher confirmed that in a laboratory environment, the clinical need for continuous biosensors is low. In contrast, Dr. Hansen confirmed the clinical importance of creatinine monitoring, particularly in intensive medical contexts such as kidney and liver transplantation or major cardiac surgery where patients are at increased risk of AKI. However, he pointed out that daily blood testing is routine in ICU settings, which drastically reduces the need for additional continuous sensor-based monitoring in this environment. Additionally, the nephrologist informed us that from a medical perspective the most frequent reasonable sampling interval for continuous creatinine measurement would be approximately every 12 hours. Based on this, we decided not to focus our use case on intensive care and hospital applications. Instead, Dr. Hansen highlighted a key insight that helped redefine our use case. Dehydration and heat are among the leading risk factors for AKI, especially outside clinical settings. Furthermore, he emphasizes the role of prevention in terms of kidney diseases. To quote him: "It is frustrating to see patients only after kidney damage is advanced. With earlier detection, we could start treatment sooner and prevent serious complications." Based on the fact that Europe and Germany have a developed healthcare system and a mild climate, we shifted our focus to more vulnerable regions. El Salvador emerged as highly relevant due to high temperatures, frequent heatwaves, poor water access, and exposure to nephrotoxic agrochemicals, which are common risk factors

for kidney damage, especially among rural workers (Aguilar et al., 2023; García-Trabanino et al., 2015).

To further validate the relevance of our biosensor in regions with increased risk of kidney damage, we conducted interviews with Salvadorean nephrologists, Dr. Navas, Dr. Gómez, Dr. Mejia and two patients with chronic kidney disease. The physicians emphasized that kidney disease in El Salvador is frequently diagnosed at advanced stages, especially in rural areas with limited access to specialists. The nephrologists highlighted the absence of preventive care and low health literacy as major barriers to early detection. They pointed out that nearly all their patients arrive when the disease is already chronically developed. Dr. Navas described a real need for earlier intervention tools and saw potential in a wearable device, particularly for acute monitoring and transplant care. She also noted that regular creatinine checks are necessary every 24 hours or even every 12 hours during medication or hydration adjustments. Dr. Gómez and Dr. Mejia emphasized that while creatinine alone is not sufficient for diagnosis, tracking its trends over time could help stratify patients by risk. They identified farmers and rural workers as a particularly vulnerable group. Due to prolonged heat exposure, dehydration, use of painkillers, and contact with nephrotoxic pesticides, they are at high risk of developing Mesoamerican nephropathy, a non-traditional form of chronic kidney disease that often affects young men. A wearable device that could indicate when hydration or medical care is urgently needed could have significant public health impact in this group. This confirms the sensor's potential in a preventive health application. Additionally, we spoke with two patients from El Salvador. One patient, who lived for years without access to consistent care and now requires dialysis three times a week, noted that a wearable device could have helped him detect elevated creatinine levels earlier and potentially slowed the progression of his disease. For the second patient living with chronic kidney disease, real-time feedback between doctor visits would give a greater sense of safety and help make better-informed decisions about daily health. She emphasized that accessibility is essential, highlighting that medical technology must be affordable and available to all, as healthcare should not be a privilege but a right.

In summary, the interviews in El Salvador confirmed that a wearable biosensor could be a valuable tool for early detection, especially in rural and high-risk communities where environmental factors and limited healthcare access compound the risks of kidney disease. While the sensor cannot replace comprehensive diagnostics, it can provide preventive care and empower both patients and doctors in managing kidney health more effectively. To reach these users, we are considering distribution via the government or NGOs.

4.2. Design of validation study

Our expert interviews revealed that El Salvador faces a major public health crisis. Chronic kidney disease of non-traditional origin is the second leading cause of death among Salvadoran men and the third leading cause of hospital deaths in adults (Orantes-Navarro et al., 2019). This epidemic of chronic and acute kidney disease is especially severe in rural farming communities and is driven by heat stress, agrochemical exposure, sugary drinks and dehydration. The healthcare system is under strain and specialized care is often inaccessible to rural farmers, who are disproportionately affected due to occupational and environmental risks (García-Trabanino et al., 2015). The number of nephrologists is notably low, with only 9 physicians per million inhabitants (Wainstein et al., 2021). To address this use case, our team proposes the Kidney Health System (KHS), a sensor-based monitoring solution tailored for agricultural workers in El Salvador. KHS is designed to enable early detection of kidney dysfunction and promote preventive health behavior as shown in Figure 8.

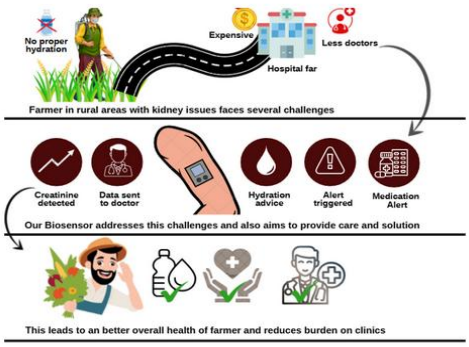

Figure 8: Functionality of KHS.

Medically, the KHS aims to detect elevated GFR, creatinine and electrolyte levels early, especially in settings where risk factors for kidney disease are prominent. A wearable sensor measures the biomarkers in ISF. The device is small, skin-compatible, water-resistant, and optimized for about one month of use. Data is transmitted via Bluetooth to a smartphone app, where it is processed. A 20% increase in creatinine levels, a critical threshold consulted by Dr. Hansen, triggers an immediate alert from KHS. This notifies the patient via an app and acoustic warning and a physician via email. Furthermore, the system offers app-based real-time hydration reminders and dietary tracking to reinforce its preventive character. By enabling early intervention and reducing the burden on specialized physicians, KHS strengthens kidney care in vulnerable rural communities.

Identifying the critical aspects of the KHS is essential to ensure a structured and reliable validation process. As a Germany-based project, one key challenge is to effectively engage the target group such as doctors and patients, ensuring their comfort with new health technologies and personal tracking tools. Therefore, KHS usability and its interface must be intuitive even under stress. The device should be comfortable, easy to use, also for individuals with low educational backgrounds, and kept as simple as possible. A smart reminder function should support users in taking health-related actions without causing alarm fatigue or overwhelm. In case of critical creatinine levels, alerts must be clearly

presented and guide the user on next steps. Seamless integration into clinical workflows is equally important. KHS must support, not disrupt, physicians' routines by offering clear alerts and on-demand data access without adding administrative burden. Technically, the system must provide accurate, clinically valid data, ideally within 5% deviation from lab standards, and operate reliably under heat, sweat and limited internet access. To handle connectivity issues, local data storage and asynchronous transmission are required.

We propose a two-phase validation study to empirically assess the usability, acceptance and systemic relevance of the KHS. This research will address key questions about the system's effectiveness in preventing dehydration and kidney injury, as well as user acceptance of its reminder and tracking functions. Phase 1 will be conducted in Germany to evaluate technical usability and clinical integration. Approximately 10 patients and 2 nephrologists should participate. Using a Wizard-of-Oz prototype (Dow et al., 2005), we will simulate core functionalities: participants will receive a mock wearable sensor and a mobile app that provides simulated measurements, alerts and hydration or medication recommendations. A physician dashboard will allow simulated monitoring. The study will span 7 days, during which, participants will complete daily digital surveys assessing usability, perceived usefulness, and behavioral response. Structured exit interviews will gather insights on system integration within clinical workflows and user acceptance.

Phase 2 will be conducted in El Salvador, targeting rural agricultural workers as the core user group. This field study focuses on contextual fit, cultural acceptance, and practical usability. Ten participants, supported by two local physicians, will use an improved version of the Wizard-of-Oz prototype with a Spanish-language interface. Onboarding and instructional materials will be adapted for non-specialist users. Over a 20-day period, participants will document their experiences in interview-style diaries, followed by final reflective interviews to assess perceived value and willingness to use the system long-term. The transition from the German in the El Salvadoran environment could become difficult as we are facing two different socio-cultural and economical environments. Which leaves us with uncertainty and needs to be further investigated. The validation study will establish a foundation for the development by assessing KHS´s medical relevance, user acceptance and its viability in local health structures for patients and physicians. In agricultural communities, 18% to 40% of adults are affected by kidney disease and this rate increases to 40% among men in high-risk areas such as Bajo Lempa in El Salvador. Therefore, an estimated 630,000 to over 1.5 million people are at risk. A real-time, wearable kidney biosensor could provide a solution by enabling earlier detection, improving access to timely interventions, and significantly reducing hospitalizations and mortality in these vulnerable populations (Orantes et al., 2014; Vela et al., 2014).

Team and support

5.1. Contributions of the team members

Name	Group	Main Role / Contribution
Elif Deniz Cali	MR	Designs and runs experiments, ensures intergroup information flow, and presents results.
Gabriela Avila	PT	Supports electrode printing, manages workflows/deadlines, handles social media, and conducts stakeholder interviews.
Julia Hoffmann	PT	Leads specialist team, optimizes electrodes, research on hardware, and develops business plan via market research and interviews.
Lucile Carmona	RI	Implements Sensit Smart controls into the UI and hardware, updates sponsors.
Marie Erceau	CD	Designs MC in 3D and tests prototypes to select the best design.
Marius Finder	PT, CD	Designs electrodes, performs measurements, and interviews potential users/physicians.
Minoo Montazeralih	PT	Optimizes and prints electrodes, analyzes data, and presents updates in meetings.
Prasidh Hota	MR	Plans/optimizes lab experiments, maintains social media, and creates brochures/visuals for the business plan.
Sara Haidari	PT, RI	Works on electrodes and hardware (heating), supports software tasks, and coordinates documentation.
Sina Junkers	MR	Conducts lab work and quality tests, and creates marketing materials (flyers, Instagram, LinkedIn).
Tabea Langer	PT, RI	Processes and evaluates experimental data, develops concentration-determination algorithm, and assists with electrode printing and hardware testing.
Xiaochen Ning	RI	Builds GUI framework and layout, produces videos, and creates social-media content.

5.2. People who have given support

We gratefully acknowledge:
Leonie Maria Holderbach, Philipp Karnop & Hana Kim (M.Sc.): Guided us as coaches with a clear, structured process and constant availability for support.
Tim Weber, M.Sc.: Offered attentive review and invaluable feedback on our concept.
Prof. Dr. Andreas Blaeser: Hosting the TUcanSense team at his institute and providing all necessary resources. **Prof. Dr. Preu:** Provided expert advice on optical methods during research, forming our project's scientific basis.
Thorsten Euler: Introduced and supported us in the screen-printing process at the printing machines.
Dr. Andreas Christmann and Prof. Dr. Harald Kolmar: Providing a lab space to work during the competition.
Michael Zoppelt, Andreas Kramer, Jakob Fritz & Sven Robin Suppelt: Contributed hands-on expertise in gold plating, 3D printing, and heating-device development.

5.3. Sponsors and partners

5. Final remarks

This project has proven to be so much more than a technical exercise: it has been an invaluable opportunity to grow, collaborate across disciplines, and transform classroom learning into real-world impact. For many of us, it marked the first chance to test our knowledge in a practical context and watch theory come to life.

We are especially grateful to have worked on a challenge of genuine significance. Designing a biosensor capable of detecting acute kidney injury is not merely an academic pursuit, but a contribution toward improving patient care. That purpose fueled our enthusiasm and made every late night and setback feel truly worthwhile.

Our sincere thanks go to our sponsors, supervisors, university staff, and everyone who lent their support. Your guidance, patience, and encouragement were indispensable to our progress.

Even after the competition concludes, we remain committed to advancing this biosensor, refining its accuracy, exploring additional applications, and taking the first steps toward clinical validation.

Finally, we extend our gratitude to the jury and organizers for creating a forum where students are empowered to innovate, explore, and believe in the impact of their ideas.

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7. Appendix

Appendix A

To evaluate the extent of the heat transfer to the potentiostat during a heating period of 30 seconds, the following assumptions and calculations are made:

$$T_p(t) = T_e(t = 0s) - (T_e(t = 0s) - T_p(t = 0s)) \cdot e^{\frac{-t}{\tau}}$$

$$\tau = \frac{s \cdot m \cdot c}{\lambda \cdot A} = \frac{0.02m \cdot 0.002kg \cdot 385J/(kg \cdot K)}{317W/(m \cdot K) \cdot \pi \cdot (\frac{0.001m}{2})^2} = 61.89s$$

$$T_p(30s) = 50°C - (50° - 30°) \cdot e^{\frac{-30s}{61.89s}} = 37.68°C$$

We denote the temperature at the potentiostat as T_p, and the initial temperature at the electrode head as T_e. We assume the distance between the electrode head and the potentiostat to be 2 cm, the mass of the conductor to be 2 g, and the specific heat capacity of copper to be 385 J/(mK). In addition, the thermal conductivity of gold is denoted by λ, and the surface of the electrode head is approximately circular. Since the area is not entirely covered in gold, we estimate the diameter to be 1 mm.

This analysis shows that the final temperature transferred to the potentiostat area may be around 37 °C, which would remain within the acceptable tolerance range for both the EmStat Pico and the potentiostat housing.

Appendix B

Algorithm 1: Concentration Algorithm

Input: measured current of sample s, current over concentration $A(c)$, residue over concentration $B(c)$, current of reference ISF measurement s_0, concentration of previous sample c_p

Output: concentration of sample x

$s_{norm} \leftarrow ||s - s_0||$; /* compute relative value of current */

$s_{max} \leftarrow \max(s_{norm})$; /* find peak of s_{norm} */

if c_p *is not* 0 **then**

  $s_{correction} \leftarrow s_{max} - B(c_p)$; /* correct peak by subtracting residue */

else

  $s_{correction} \leftarrow s_{max}$

end

$x^\star \leftarrow \arg\min_x ||A(x) - s_{correction}||$

Appendix C

The SD provides a measure of the absolute dispersion of repeated measurements:

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (x_i - \underline{x})^2}$$

where x_i are individual current readings, $\underline{x}$ is the mean current, and n is the number of replicates. To enable comparison across different signal amplitudes, the RSD is also computed:

$$RSD = \left(\frac{SD}{\underline{x}}\right) \times 100$$

Appendix D

Concentration (µM)	Mean E1 (µA)	SD E1	RSD E1 (%)	Mean E2 (µA)	SD E2	RSD E2 (%)
10	189.95	5.46	2.88	143.19	4.67	3.26
25	199.98	5.31	2.65	178.30	4.51	2.53
50	570.81	11.72	2.05	442.06	21.07	4.77
75	609.98	0.59	0.10	535.92	29.70	5.54
100	873.46	12.47	1.43	759.64	30.49	4.01
150	1152.61	18.81	1.63	1075.20	26.93	2.50
200	1413.71	32.47	2.30	1344.97	5.74	0.43
300	2315.02	2.00	0.09	1515.91	0.40	0.03

Table 1 - Statistical summary of peak current measurements for two electrodes (E1 and E2) across creatinine concentration

Concentration (µM)	Mean E1 (µA)	Mean E2 (µA)	Absolute Difference (µA)	Inter-electrode Variability (%)
10	189.95	143.19	46.76	28.30
25	199.98	178.30	21.68	11.34
50	570.81	442.06	128.75	25.08
75	609.98	535.92	74.06	13.06
100	873.46	759.64	113.82	13.93
150	1152.61	1075.20	77.41	6.96
200	1413.71	1344.97	68.74	5.06
300	2315.02	1515.91	799.11	42.31

Table 2 - Inter-electrode variability calculated from mean peak currents of E1 and E2

Appendix E

Relative difference in mean current between E1 and E2:

$$\text{Inter-electrode variability}\,(\%) = \left(\frac{|\overline{x_{E1}} - \overline{x_{E2}}|}{\frac{1}{2}(\overline{x_{E1}} + \overline{x_{E2}})}\right) \times 100$$

Appendix F

Name	Role/Specialization	Institution	Country
Dr. Ana Luisa Navas Figueroa	Nephrologist – Internal Medicine – Pregnancy-related Hypertension	Private Clinic	El Salvador
Dr. Joaquín Armando Mejía Rodríguez	Nephrologist – Internal Medicine – Kidney Transplantation	ISSS and Private Clinic	El Salvador

Dr. Mario Nelson Gómez Mejía	Nephrologist – Renal Ultrasound (Targeted Biopsy) – Internal Medicine	ISSS and Private Clinic	El Salvador
Dr. Marlon Iván Reyes González	Intensive Care Specialist – ICU	General Hospital ISSS and Private Clinics	El Salvador
Dr. Matthias Hansen, M.D.	Chief Senior Physician – Nephrologist	Clementine Kidney Centre, Frankfurt	Germany
Dr. Schumacher	Laboratory Physician	Klinikum Darmstadt	Germany

Patient	**Condition(s)**	**Country**
Patient 1	Lupus with kidney involvement (lupus nephritis) – membranous glomerulonephritis	El Salvador
Patient 2	Cervical cancer; bladder removal (cystectomy); recurrent kidney infections; reduced kidney function (~30%)	El Salvador
Patient 3	Diabetes; elevated creatinine levels; kidney failure (currently undergoing dialysis)	El Salvador
Patient 4	Alport syndrome – kidney transplant	El Salvador
Patient 5	Steroid-resistant nephrotic syndrome	Germany
Patient 6	Membranous glomerulonephritis – chronic kidney disease	Germany

Appendix G

Summary of questionnaire for medical professionals interviews

To evaluate the clinical relevance and implementation feasibility of a continuous kidney monitoring system, a series of semi-structured interviews were conducted with physicians. The questions explored both medical utility and health system constraints. Physicians were asked about their experience treating patients with advanced kidney disease, especially AKI, and their current methods of monitoring kidney function. They were also prompted to reflect on the potential benefits, limitations, and safety concerns of a wearable device for continuous monitoring of creatinine and related biomarkers. Key topics included measurement intervals, response strategies to abnormal readings, integration into clinical systems, and suitability for different patient groups (transplant recipients, ICU patients). Additionally, the interviews addressed broader healthcare system challenges, particularly within El Salvador. These included questions about insurance coverage, access to nephrology services in rural areas, diagnostic delays, the impact of agrochemical exposure, and the role of telemedicine. Physicians were also asked about barriers to early detection,

current preventive strategies, and whether patients tend to delay medical consultation due to financial or logistical reasons.

Summary of questionnaire for patient interviews

To understand the lived experiences of individuals with kidney-related illnesses and assess the potential value of continuous monitoring solutions, semi-structured interviews were conducted with patients across a range of conditions including glomerulonephritis, steroid-resistant nephrotic syndrome, and cancer-related kidney impairment. The interviews covered three main areas:

1. General Patient Experience – Questions focused on the patient's diagnostic journey, routine interactions with healthcare providers, risk of relapse or progression, lifestyle impact, and attitudes toward using continuous measurement tools, including willingness to pay for such devices.
2. Specific Clinical Management – This section explored clinical markers such as creatinine and GFR, dialysis routines, the role of monitoring between sessions, transplant complications, check-up frequency, mental and physical burdens, and opinions on the usefulness of at-home or wearable monitoring technologies.
3. Cancer-Related Kidney Risk (Special Case) – For patients with secondary kidney damage due to cancer or related treatments, questions addressed their unique diagnostic challenges, current treatment barriers, frequency and affordability of medical visits, and their perspectives on self-monitoring, healthcare access, and disease outlook.