ELEC-E7840- Smart Wearables

Project Description
Spring 2026

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Sensor-based motion recognition is a cutting-edge technology that enables the interpretation of human movements using various sensors and advanced algorithms. By capturing and analysing hand gestures or body motions, this technology translates human actions into commands, offering a natural and intuitive way to interact with digital devices and systems. Motion recognition has found applications in a wide range of fields, from consumer electronics and gaming, where it enhances user experience and control, to healthcare, where it aids in remote patient monitoring and surgical procedures. In the automotive industry, it improves driver safety and infotainment control. Moreover, motion recognition plays a vital role in extended reality, making immersive experiences more interactive and engaging. Its versatility and potential for enhancing human-machine interaction make sensor-based motion recognition a transformative technology in the modern era.

Topic description

In this project, you are expected to form a small group of up to 3 students to develop one of the following wearable systems.

- **(Topic 1) Smart gloves for American Sign Language (ASL) alphabet recognition**
- **(Topic 2) Textile-based wearable calculator**
- **(Topic 3) Smart socks and/or knee pads for physical activity recognition.**

The project consists of the design, implementation and evaluation of both hardware and software. This would allow you to practice all the skills you have learnt from the course, from creating textile-based sensors to integrating sensors into textiles to collecting data using Arduino to developing machine learning algorithms for processing sensor readings and to running user tests. Detailed evaluation criteria can be found from the table at the end of this document.

Topic 1: Smart Gloves for ASL alphabet recognition

Based on your group size, you should select a minimum of 4 letters for a one-person group, 6 letters for a two-person group, or 8 letters for a three-person group from the alphabet, and develop one or a pair of smart gloves to recognize these letters through hand gestures. The gloves should be able to classify gestures into the designated set of letters or labelling them as unknown. In other words, it is a multi-class classification problem. If recognizing 4 letters, a five-class classification model is required. Both classification accuracy and the wearability of the smart gloves are essential evaluation criteria.

It's advisable to avoid suggesting simplistic mappings, such as assigning one switch to correspond with one class. Each project is permitted to use up to 2 on/off switches as sensors.

For an introduction to the ASL alphabet, please refer to this YouTube video:
https://youtu.be/DBQINq0SsAw?si=n1ykZcgfuCXeTeFu

Topic 2: Textile-based wearable calculator

The textile-based wearable calculator is designed to recognizes handwritten Arabic numerals (0 – 9) from hand gestures, and facilitate basic arithmetic operations, specifically the addition and subtraction of positive integers. For example, the calculator should be able to compute calculations such as 90 – 5 = 85, or 211 + 32 = 243. You may implement three arithmetic operators (+, - and =) and a backspace key using textile-based on/off switches.

Depending on your group size, please select a minimum of 4 digits (e.g., 0, 1, 2, 3) for a one-person group, 8 digits for a two-person group, or all 10 digits (0-9) for a three-person group.

The calculator can be designed in any shape or size, and can be placed on any part of the body that you find convenient for use. Results of calculation can be displayed on the screen of a computer connected with the pad, or through alternative methods (e.g., spoken output, LED lights).

Both the accuracy in numeral recognition and the overall wearability and usability of the calculator will be essential evaluation criteria.

Topic 3: Smart Socks and/or Knee Pads for Physical Activity Recognition

You will develop smart socks and/or knee pads to recognize the following activities:

1) Walking on a flat surface: detect whether the person is walking forward or backward and count the steps in each direction.
2) Climbing stairs: identify whether the person is climbing up or down and count the steps
3) Sitting on a chair: detect if the person is sitting with both feet on the floor, or sitting cross-legged
4) Sit-to-stand: detect if the person rises from a seated position and count how many seconds it takes.
5) Standing: detect if the person is standing, and if the person is standing upright or leaning to one side (left/right)

The requirements will vary with the size of your group:

- One-person group: You must recognize at least 1) walking (counting steps), 3) sitting on a chair (two poses), and 4) sit-to-stand. It is not required to differentiate between walking forward and backward.
- Two-person group: You must recognize at least 1) walking, 2) climbing stairs, 3) sitting on a chair (two poses), 4) sit-to-stand, and 5) standing. It is not required to differentiate moving directions and specific standing poses.
- Three-person group: You must implement 1) – 5).

If an activity does not fall within the predefined categories, the system should label it as unknown or others.

In this project, you are restricted to using textile-based sensors, such as pressure sensors, bending sensors and strain sensors in this project. IMUs are not permitted. Please take into account that different people may perform the same activity in different manners. Both classification accuracy and the wearability of the smart garments are essential evaluation criteria.

Hints: You can find some reference designs from the recommended reading list on MyCourses. It is allowed to borrow some designs from the literature, but you must be able to explain the reasoning behind your design choices in your presentations.

Materials and tools provided

From the course, you are provided with some materials for creating the prototypes. You are also allowed and encouraged to use additional materials you may have access to, to make the prototypes better. Apart from the ESP32S3 and breadboard, you can keep the prototypes you made. Materials provided by the course include:

- SEEED XIAO ESP32S3 Presoldered

- Conductive fabric and yarn
- Piezoresistive fabric
- A breadboard, and a set of resistors and wires

Step-by-Step Guide

We suggest that you complete the assignment following the steps below. If you will only attend the first half of the course, you need to complete at least Step 1- 5. Remember to document the process in your group's work diary.

Step 1: Requirement analysis

Identify the functional and non-functional requirements of the smart garment you are going to create. Regarding functional requirements, you need to define the gestures/activities to be recognized. Regarding non-functional requirements, besides recognition accuracy, you should consider at least the **wearability** of your design. Though it is not required by this assignment, it is recommended to consider other factors such as usability, cost efficiency and aesthetics.

Step 2: Ideation

Which sensors would you use? Where to place these sensors? Are these sensors sensitive enough for recognizing different gestures? Are the sensing ranges of these sensors large enough? In this step, you may need to create simple sensor prototypes and try out different designs. Keep in mind that it is an iterative design process. To figure out the optimal selection of sensor types and the placement of sensors on the garment, you would need to create prototypes and improve them based on the test results. It is important to document the designs and test results of different prototypes and explain later in the final presentation or your work diary how the design evolves (e.g., did you modify a sensor to enhance sensitivity, or did you eliminate redundant sensors after comparing classification results?)

Step 3: Design

Based on what you have learnt from the previous step, you can create a design. Pay attention to the wiring and circuit design, and consider the non-functional requirements listed in Step 1. From the wearability perspective, you may consider whether the prototype is comfortable and easy to wear (e.g., not too heavy, soft, easy to put on and remove, durable) and check if the prototype allows natural movements without restriction. You may evaluate the wearability through user testing. For instance, you can gather a diverse group of potential users to wear and interact with the prototypes. Observe their feedback, comfort levels, and any discomfort they experience during use. From a cost efficiency perspective, you can consider the cost of production. Can you achieve the same performance with less sensors? Is the design simple and easy to manufacture?

Step 4: Prototyping

Create a prototype. The prototype should be able to collect sensor readings using Arduino and forward the data further to a computer.

Step 5: Data collection and pre-processing

Hire a couple of subjects. Collect and label sensor readings corresponding to different gestures/activities. Remember that you can do processing on the data, such as normalizing or combining sensor output values. Please refer to a separate document about guidance on data collection and pre-processing.

Step 6: Model training

Divide the collected data into training, validation and testing sets. Train a machine learning model to recognize the gestures/activities. You can try different machine learning models and choose the best one. *Remember to include an 'unknown' or 'other' class to cover the gestures/activities outside the pre-defined set.*

Step 7: Result analysis

Analyze the results of Step 6 and decide if you need to modify your design. In practice, you may need to iterate Step 3 to 6 a couple of times. Remember to present the test results of your final model in your final report.

Keep in mind that you should report the test results of subjects not included in your training dataset. For instance, if you have collected data from 20 subjects, you should not use all of their data for training the machine learning model. Instead, you might use data from 14 subjects for training and validation and reserve data from the remaining 6 subjects for testing.

Step 8: Deployment and user testing

After you get a machine learning model that fulfils your functional requirement, you can deploy it on a computer that connects with ESP32S3 via Bluetooth or Wi-Fi. The sensor readings can be sent in real time to the computer for processing. You can measure how long it takes since the data is captured until the recognition results are returned. If the latency is too long (e.g., several seconds), it would affect the user's experience.

It is highly recommended to run a user test to evaluate the wearability and usability of the final prototype. It can be done through the following questionnaires. If you only complete the first half of the course, it is still recommended to run a user test to evaluate the wearability of the design.

- Norene Kelly and Stephen Gilbert. 2016. **The WEAR Scale**: Developing a Measure of the Social Acceptability of a Wearable Device. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16). Association for Computing Machinery, New York, NY, USA, 2864–2871. https://doi.org/10.1145/2851581.2892331
- Brooke, Johan. (1996). **SUS - a quick and dirty usability scale**

How to work in a team?

- Clearly define roles within the team, ensuring each member has a distinct responsibility.
- Schedule regular team meetings to discuss progress, challenges, and to ensure everyone is on the same page.
- Encourage the use of collaborative tools for project management, document sharing, and communication.
- Implement a peer-review system for team members to provide constructive feedback on each other's contributions.
- Incorporate team-building activities to foster a positive and collaborative team culture.

Deliverables

During the project, you will produce many things, including program code, electronic circuit design, gloves with integrated sensors. To show your work, we expect the following deliverables:

- Code repository
- Circuit diagram
- Demo
- Presentation (slides)
- Summary of your work diary

Code repository

This should include both Arduino and machine learning code.

Circuit design

If the prototype has all the sensors and wiring well integrated, it is difficult to see how it is all connected, so provide us with the circuit design (diagrams). You can upload a separate document of your circuit design or include the diagrams directly in your final presentation.

Demo

We want to see the garment working, so provide a live demonstration of the garment working. You can simply show the name or symbol of the recognized gesture/activity in real time on your computer display or convert the results into spoken words. It is also acceptable if you, for example, turn on a LED light that corresponds to the recognized gesture or activity. It is not required to implement more complex user interfaces for demonstration.

Presentation (no page limit)

This is what most of the grading will be based on. We want to hear how you approached the task, what problems you ran into, how you solved them, as well as the final solution. There is plenty of content we request you include, and for the sake of getting a coherent story, some filler. Suggested parts to include are:

1) Sensor design

What did you want to measure with the sensor? How did you try to achieve this? How does the sensor work? What kind of measurement range does it have (e.g., resistance min, max)? How sensitive are the sensors? Did you have variance between the sensors?

2) Garment design

How did you choose which sensors to use and where to place them? How did you integrate the sensors and circuit into the garment? What materials and manufacturing techniques did you use? Did you do iterations? What was learned at each stage and how did you improve the design accordingly? What would you improve upon if you continued with the development? You can include the diagram of your circuit design in this part. Also remember to explain the design choices from wearability perspectives. Please include quantitative comparison of designs where available.

3) Software design

Do a high-level overview of your software architecture. What gets calculated where? How do you send data from one place to another?

4) Machine learning model

Machine learning and AI are at their best when explainable. That starts from explaining how the data can be used to get to the output values, rather than just throwing some data in a black box and hoping for the best. Explain how the system turns raw sensor measurements into recognized gestures/activities. What kind of data did you collect? Did you do further processing on that data? What machine learning model did you choose and why? How accurate is your model, on the training set, and on a validation set?

5) Test results

Include in this part the recognition accuracy of each gesture/activity. It is necessary to test the prototype with subjects (i.e., users of the smart wearables) excluded from the training/validation sets. Please evaluate if the accuracy drops when you test on a different subject. (e.g., comparing the results of validation set vs. test set). It would be helpful to include a confusion matrix. In addition to evaluating pre-defined activities and gestures, it is essential to assess the frequency with which other or undefined activities and gestures are misclassified as one from the predefined set, and vice versa.

Please also include the test results of wearability and usability here if available.

6) Teamwork

Please provide a brief explanation of your teamwork approach, including how you distributed the workload and allocated tasks, managed the project, and addressed conflicts or challenges. It is important to distribute the workload evenly and ensure that each team member is actively contributing at every stage of the design process. Avoid assigning isolated tasks, such as having one person solely responsible for hardware prototyping and another for machine learning solution development. It's crucial to prevent free-riding and ensure all members are engaged throughout.

Hints: It is strongly encouraged to review papers from the recommended reading list to gain insights into effectively presenting your design and evaluation results with precision.

Grading of the project work

For students who complete both Period III and IV (6 ECTS), you can collect up to 30 points from the **mid-term review**, up to 66 points from the **final review**. If you complete only the first half of the course, you just need to complete the mid-term review at the end of Period III.

Table 1: Assessment criteria for the mid-term review

Topic (weight)	**Not acceptable (0)**	**Marginal (1)**	**Acceptable (2)**	**Exceptional (3)**
1.Garment design - the selection of sensor type, sensor layout and integration of electronics into textiles (3)	The design is not technically sound	The design can in theory recognize most of the required gestures or activities.	The design can in theory recognize all the required gestures/activities. The design requires enhancement to improve wearability.	The design is technically sound and effectively addresses potential wearability issues and cost efficiency.
2. Sensor fabrication and characterization (4)	No working sensors	Sensor prototypes are created. Sensor	Sensors have been fabricated and characterized.	Sensors have been fabricated and characterized. The sensing ranges and sensitivity of the sensors fulfil the application

		characterization has not been completed.		requirements. The evaluation results are clearly documented.
3. Data collection (3) **Live demo is required.**	Not considered	Partially addressed	Sensor data can be collected simultaneously from more than one sensor.	Additionally, data from all sensors can be collected simultaneously and transmitted in real time via BlueTooth or Wi-Fi to a connected computer.

Table 2: Assessment criteria for the final review

Topic (weight)	**Not acceptable (0)**	**Marginal (1)**	**Acceptable (2)**	**Exceptional (3)**
1 Recognition accuracy for the minimal set of gestures/activities (10)	< 70% Or the prototype is not working	Average accuracy is over 70%.	For the testing set, the recognition accuracy of each gesture/activity is over 80%. Confusion matrix is provided. For Topic 3, we evaluate also the accuracy of step counting.	For the testing set, the average recognition accuracy is over 85%, and the recognition accuracy of any pre-defined gesture/activity is over 80%. Confusion matrix is provided. No significant cross-subject performance degradation.
2. Final sensor design and placement (2)	The design is not technically sound	The final design is technically sound but reasoning about design choices is not clearly explained	The final design is technically sound and is well explained.	The final design is technically sound and is well explained. The iterative design process is explained with sufficient details (e.g., experimental results that help make design decisions)
3. Wearability and Usability (5)	Not considered	Partially addressed	The design is easy and comfortable to use, does not restrict natural movements, and the hardware prototype seems to be durable.	Additionally, the results of user testing (at least 5 test users) prove the wearability and usability of the design.
4. Live Demo of the whole system (5)	Not working	Partially working	It functions as designed, but its	It operates with high performance and robustness

			robustness could be enhanced.	

Clarification on the criteria:

1) **Selection of sensor types and placement of sensors**: Is the design technically sound? Can students articulate the rationale behind their chosen sensor types, and placement?
2) **Sensor characterization**: It is required to measure at least sensing ranges and sensitivity, and assess if these fulfil the application requirements. For example, is the sensing range of a pressure sensor placed on socks adequate?
3) **Accuracy of gesture/activity recognition**: The test results should include multiple subjects (at least 5 subjects not included in the training set), covering both the pre-defined gestures and the other (undefined) gestures. Please pay attention to **cross-subject performance degradation**. We will check the performance of the prototype during the demo session, as well as the detailed result analysis included in the final presentation.
4) **Wearability**: comfortable to wear, easy to put on and remove, does not restrict natural movements of hands/feet, does not easily get broken. Does the design consider these factors? How about the results of the user testing? You may present the results of your questionnaires.
5) **Demo**: it is acceptable if the demo occasionally fails (e.g., crashing mid-process but easily resuming after a restart).

If a member of a student group withdraws from the course or leaves after Period III, the adjusted group size will be considered during the final review. During the course, it is allowed to merge groups as long as the total number of students does not exceed 3.

Grading of the course

Besides the project work, you will collect more points by submitting the summary of work diary and an individual essay when you complete the course.

Summary of work diary (no page limit): Max. 2 points. The work diary documents the iterative design process and teamwork dynamics.

Individual essay: reflect on what you have learnt and what are the biggest challenges you faced and how you addressed them. Max 2 pages. Max. 2 points.

The final grade for **3-ECTS version** depends on the total amount of points you have collected from mid-term review and individual essay (max. 32 points).

- 16-18 points: 1
- 19-21 points: 2
- 22-25 points: 3
- 26-28 points: 4
- 29-32 points: 5

The final grade for **6-ECTS version** depends on the total amount of points you have collected from project work and other assignments (max. 100 points).

- 60-69 points: 1
- 70-74 points: 2
- 75-79 points: 3
- 80-89 points: 4
- 90-100 points: 5

Appendix: What you may want to document in a work diary

Project Overview:

- Briefly describe the project's goals, objectives, and scope.
- Outline the target audience and user personas.

Project Timeline:

- Include a timeline or schedule with milestones and deadlines.
- Note any deviations or adjustments to the original timeline.

Research and Discovery:

- Document research methods and findings related to user needs, and existing solutions
- Note any insights gained from user interviews, surveys, or observations.

Conceptualization and Ideation:

- Capture brainstorming sessions and idea generation.
- Document initial sketches, mind maps, or concept diagrams.
- Record discussions and debates regarding design directions.

Prototyping and Iteration:

- Outline the prototyping process, including tools used and design decisions made.
- Document user testing sessions, noting feedback and areas for improvement.
- Describe iterations and refinements based on user feedback.

Technical Development:

- Detail the technical aspects of the project, such as coding, hardware integration, or software development.
- Note challenges encountered and their resolutions.
- Document any changes in technology or tools used.

Collaboration and Teamwork:

- Record team meetings, decisions, and collaboration efforts.
- Highlight contributions from team members and acknowledge teamwork.
- Note any conflicts or challenges within the team and how they were addressed.

Feedback and Evaluation:

- Document feedback received from stakeholders, mentors, or clients.
- Include reflections on the feedback and how it influenced design decisions.
- Evaluate the project against initial goals and objectives.

Challenges and Solutions:

- Detail challenges faced during the project and the strategies employed to overcome them.
- Document any unexpected issues and their resolutions.

Visuals and Design Artifacts:

- Include images, sketches, wireframes, prototypes, or any visual materials that represent the project's evolution.
- Attach relevant design files, screenshots, or multimedia elements.

Final Deliverables:

- List and describe the final deliverables.
- Reflect on how well the final outcome aligns with the initial project goals.

Next Steps:

- Outline any recommendations for future iterations or improvements.
- Suggest potential areas for further exploration or research.