# Principles and Design of IoT Systems

[INFR11150]

School of Informatics, University of Edinburgh

*Coursework 1 – Released on 21 Sept. '22, Deadline: 7 Oct. '22*

*Coursework 2 – Released on 23 Sept. '22; Deadline: 28 Oct. '22*

*Coursework 3 – Released on 21 Sept. '22; Demonstration on 23 Nov. '22; Final report: 20 Jan. '23*

**Please contact Professor D K Arvind (dka@inf.ed.ac.uk) if you have any questions**
**Version 0.1, updated 7 September 2022**

## Course Overview

Welcome to the Principles and Design of IoT Systems (PDIoT) course!

You will experience the different facets of designing and implementing a complex IoT system, from specification to demonstration of a prototype implementation, over the course of 10 weeks). Working in small groups, you will produce a real-time human activity recognition system, using wireless Inertial Motion Unit (IMU) sensors and machine learning techniques.

The practical work will be complemented by knowledge gained through personal research on foundational topics in Internet of Things and distilled in a 3000-word essay.

Each student will also collect labelled motion data, for a set of prescribed physical activities. This will contribute towards a common dataset, to be used for for training and testing their implementation.

Each group will be provided with the following hardware:

- **Respeck**: A compact Inertial Motion Unit (IMU) device, designed in-house, with a 3-axis accelerometer and gyroscope sensor for physical activity monitoring
- **Thingy:** An off-the-shelf IMU prototyping platform produced by Nordic Semiconductor with 3-axis accelerometer, gyroscope and magnetometer sensors

Both devices use the Nordic NRF52 System on Chip (SoC), containing a low-power Arm Cortex processor and Bluetooth Low Energy (BLE) radio for wireless communication.

## Coursework [100% of course marks]

This course is assessed purely on 3 coursework assignments, as there are no lectures or examinations. The data collection, research and implementation deliverables are described in more detail below, along with their allocation of marks.

### Coursework 1: Data Collection [15%]

- ✓ **Release date**: 21 September 2022
- ✓ **Submission date**: 7 October 2022
- ✓ **Feedback return**: 21 October 2022

Data collection by each student using the Respeck monitor worn as a plaster on the chest and the Thingy placed snugly inside the right-hand side pocket of their trousers, dress, or any other clothing.

## Coursework 2: Research [15%]

- ✓ **Release date**: 23 September 2022
- ✓ **Submission date**: 28 October 2022
- ✓ **Feedback return**: 11 November 2022

Research and compose a technical Survey Paper (max. 3,000 words) in **one** of the following topics, that will be assigned to students:

- Comparison of encryption algorithms for wearable devices in IoT systems
- Comparison of data fusion methods for estimating orientation in 3-D space using inertial motion sensors
- Comparison of networking protocols for edge devices in IoT systems
- IoT for healthcare of the elderly
- IoT in mental health
- IoT for clean environments (air pollution and global warming)

The Survey Paper should be divided into sections, with the following mark weightings:

- A brief introduction which sets the context [10%]
- The main body of the essay, divided into subsections [60%]
- Conclusions [20%]
- Bibliography (not included in the word count) [10%]

Where possible you should use (in reasonable numbers) tables, diagrams, graphs, images which don't contribute to the word count.

The 60% of marks for the body section are shared as follows: breadth of research - 20%; distillation of essential features in a scholarly manner - 40%.

## Coursework 3: Implementation and Final Report

- ✓ **Release date**: 21 September 2022
- ✓ **Progress demonstration/feedback**: 19 October 2022
- ✓ **Final Demonstration date**: 23 November 2022 (10:00 – 13:00)
- ✓ **Peer testing completion date**: 2 December 2022
- ✓ **Final report submission date**: 20 January 2023 (16:00)
- ✓ **Feedback return**: 3 March 2023

This coursework involves the development, demonstration, and final written report (max. 10,000 words) for the human activity recognition system).

### Implementation

Your task will be to implement a human activity recognition system for a set of common physical activities listed below, by applying machine learning techniques on the IMU data and displaying real-time results in an android app.

- Sitting (straight, bent forward, bent backward)
- Standing
- Lying down (left, right, on the back, on the front)
- Walking
- Running / Jogging
- Ascending and descending stairs

- Desk work
- General movement (sudden turns, bending down, getting up from chairs, anything else that doesn't qualify as an activity)

You will experience the different stages in the design and implementation of a complex system, from its specification to the demonstration of a working prototype and evaluation of its performance. You will be exposed to aspects of embedded systems programming, sensor data analytics using machine learning techniques, mobile application development, user interface design, and system integration and testing.

There will be opportunity to demonstrate progress and receive written formative feedback in Week 5. The final presentation to showcase of your prototype with a live demonstration is scheduled on Wednesday, 23 November 2022. Each group will peer review the App produced by another group and rate it according to a set of criteria. Your final written report will be due on 20 January 2023.

## Demonstration

Each group should demonstrate their prototype to the entire class on Wednesday, 23 November 2022. Each group's implementation will then be tested and marked by another group according to a set of criteria, and the results submitted by Friday, 2 December 2022.

## Documentation

An individual report describing the activity recognition system will be due by 16:00 on Friday, 20 January 2023. The final report should not exceed 10,000 words (excluding Bibliography and Appendices) and should be organised into the following chapters:

### Title Page

- PDIoT Coursework 3 (2022-23)
- Project title
- Name
- Matriculation number
- Abstract

### Introduction

- Project aims
- Brief description of the method adopted
- List the physical activities used in the classification
- Summary of results

### Literature survey

- A review of the state-of-the-art for human activity recognition algorithms

### Methodology

- A description of the system and its implementation
- Hardware and firmware
- Wireless communication
- Algorithm for human activity recognition
- Mobile application
- Software organisation
- Testing

### Results

- Critical analysis of the implementation using quantitative methods
- Benchmarks

### Conclusions

- Reflection on the project
- How might you wish to extend the project and improve the implementation

## Organisation

The course has tutorial and lab sessions. Attendance is compulsory.

Students registered for this course or wishing to take this course should attend the introductory meeting at 10:00 on Wednesday, 21 September 2022. During the meeting you will form groups and take delivery of the hardware. A locker will be provided for storing equipment safely in the lab.

### Tutorials

Tutorial meetings will take place in weeks 2-5 to present progress on your research for the Survey Paper, due as part of Coursework 2. Please come prepared with 2-3 slides describing your research.

### Lab sessions

Weekly lab sessions take place on Wednesday, starting on 21 September 2022 and running for 10 weeks. The PDIoT lab is in Appleton Tower room 3.09. Student groups should sign up for **one** of the 1-hour sessions at 10:00, 11:00 or 12:00. The whole group must attend the chosen session every week.

## Schedule

### Week 1

- Introduction and formation of groups
- How to use IMU sensors and data capture app
- Discuss Coursework 1 and begin data collection

### Week 2

- Capture the requirements and use cases for the target application
- Presentation of sensor data collected in Week 1
- Discussion on approaches to data analysis or physical activity recognition
- Start development of your Human Activity Recognition algorithms
- Continue data collection of physical activity

### Week 3

- Introduction to Android development
- Development of the mobile application displaying real-time recognition of physical activity using TFLite from TensorFlow
- Submission of Coursework 1 by 16:00 on Friday, 7 October 2022

## Week 4

- Introduction to firmware development for the Nordic NRF52
- How to set up the build environment
- Flashing firmware onto the Thingy and reading the debug log

- Continue development of the mobile application
- Start Coursework 2

### Week 5

- Demonstrate mobile application displaying real-time recognition of physical activity and receive written formative feedback
- Choose **one** of the following options:
    - Further enhance the ML-based sensor data analytics within your android app

    **OR**

    - Modify the Thingy stock firmware to perform on-device activity recognition
- Receive feedback on Coursework 1

### Week 6

- Submit Coursework 2 Survey Paper
- Embedded route:
    - Algorithm migration to the Cube platform
- ML algorithm route:
    - Algorithm tuning
    - Live prediction on the Android App
- Choose **one** of the following options:
    - Focus on usability and create a polished UI

    **OR**

    - Create a backend server where you upload the ML model for generating predictions

### Week 7

- Continue your work from Week 6
- Test the algorithms:
    - Validate against off-the shelf models
    - Discuss other methods for validation (e.g., cross testing the existing models)
- Firmware or user interface testing, as appropriate

### Week 8

- Second demonstration and feedback
- Receive feedback on your Coursework 2 Survey Paper

### Week 9

- Prepare for the final demonstration in Week 10

### Week 10

- Live demonstration
- Prepare for peer review

### Week 11

- Review another group's implementation
- Start working on your final report

## Demonstration

**Week 10 (10:00 -13:00 on Wednesday, 23 November 2022 in AT3.01/3.02**

Each group is allocated 10 minutes, which should be roughly allocated as follows:

- 4-minute presentation
- 4-minute demonstration
- 2-minute Q&A

The audience is the entire PDIoT class and the course instructors. You should limit your presentation to around 5 slides and include the following:

- An annotated block diagram showing the architecture of your implementation
- The algorithms/models used for physical activity classification
- The Android App design
- The performance of the implementation:
    - accuracy
    - communication latency
    - power consumption
    - CPU cycles
    - memory usage
- Conclusions and reflections on what you have learnt during the coursework

You should next demonstrate your implementation using a combination of live and recorded data (the latter for activities which would be difficult to demonstrate live, such as climbing stairs). You should share your mobile phone screen, so that it is visible on the projector. Please rehearse your demonstration in advance, so that it works seamlessly on the day and note that time keeping will be strict!

Please upload your slides by 0900 on the morning of the demonstration. A URL will be added here closer to the time.

## Peer Review

Peer reviewing is an important part of academic research and during the course you will have the opportunity to peer review the work of a fellow group.

You should submit your code for review by 16:00 on Friday, 25 November 2022 in the advertised format.

Each group will review/test the App of another group and evaluate it according to a set of criteria. The review must be submitted by 16:00 on Friday, 2 December 2022.

## Assessment

Students will be awarded individual marks, out of 100, based on the demonstration, peer review and the final written report. Criteria for assessment are as follows:

### Presentation [5 marks]

Quality of the oral presentation, slides and demonstration.

### Peer Review [15 marks]

Marks are awarded for thorough testing and the quality of the submitted review.

## Analysis [20 marks]

Critical analysis using quantitative methods and performance analysis presented as graphs, with a balanced interpretation of the results.

## Technical evaluation [60 marks]

The following factors will be considered when marking the technical merit of the project:

- Completion of the project to produce a working prototype
- Degree of difficulty
- Quality and amount of work undertaken
- Justification of design decisions
- Software design for reusability

We specifically look for features from the following sets to determine your mark. Please note that you should implement **all** the essential features before moving onto desirable or advanced features.

### Essential features [0-41 marks]

- On-device, real-time Human Activity Recognition (ML in the Android app or custom firmware on the Thingy)
- Basic interface for users to view the current activity
- Ability for user to pair a Respeck or a Thingy
- Classification of a subset of activities:
    - Sitting/Standing
    - Walking
    - Running,
    - Lying Down
- Accuracy of 85-90%

### Desirable features [42 – 54 marks]

Accuracy of 91-95% for your basic implementation, plus at least one of the following features:

- Classification of all activities - provide cross validation accuracy
- Use of both devices (Respeck, Thingy) or sensors (accelerometer, gyroscope) to improve accuracy
- Intuitive user interface, allowing user logins and the ability to view historic data

### Advanced features [55 – 60 marks]

In addition to all Essential and Desirable features, at least one of the following:

- Enable users to calibrate the sensor to their own body
- Perform live classification in the cloud
- step counting
- >95% accuracy for Essential Features

# End

We hope that you have enjoyed the course and acquired new skills, which will be useful for future projects!

Final marks and feedback for Coursework 3 will be delivered by Friday, 3 March 2023.