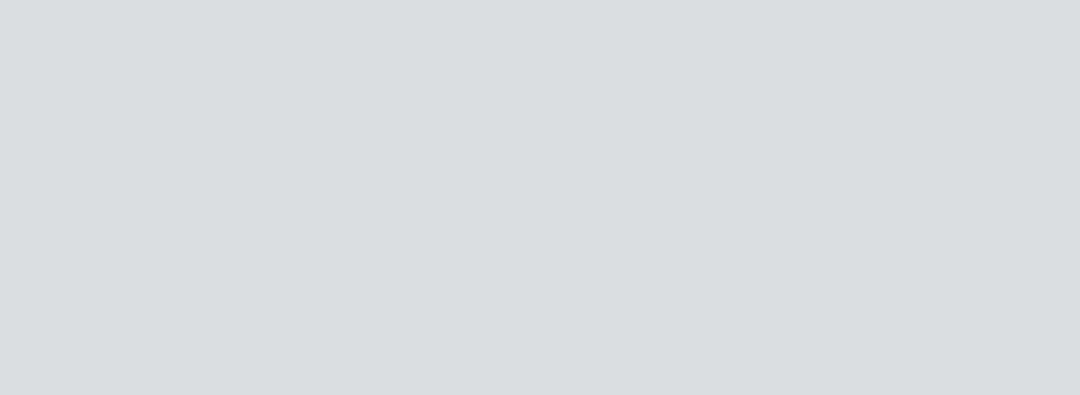
UNIVERSITATEA POLITEHNICA DIN BUCUREȘTI

FACULTATEA DE AUTOMATICĂȘI CALCULATOARE

DEPARTAMENTUL DE CALCULATOARE

A circular logo with a building in the center

AI-generated content may be incorrect.



Computer Science & Engineering Depart ment

PROIECT DE DIPLOMĂ

Analiza bazată pe inteligența artificială în mediul smart home

Un studiu în domeniul Ambient Assisted Living (AAL)

Luca Plian

**Coordonator stințific:**

### Prof. dr. ing. Alexandru Sorici

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FACULTY OF AUTOMATIC CONTROL AND COMPUTERS

COMPUTER SCIENCE AND ENGINEERING DEPARTMENT

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DIPLOMA PROJECT

AI-Powered Analysis in Smart Home Environment

A study within the domain of Ambient Assisted Living (AAL)

Luca Plian

**Thesis advisor:**

### Prof. dr. ing. Alexandru Sorici

**BUCHAREST**

**CUPRINS**

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**Sinopsis**

Sinopsisul proiectului are rol de introducere, conținând atât o descriere pe scurt a problemei abordate cât și o enumerare sumară a rezultatelor și a concluziilor. Se recomandă ca sinopsisul să fie redactat într-un limbaj accesibil unei persoane nefamiliarizate cu domeniul, dar în același timp destul de specific pentru a oferi rapid o vedere de ansamblu asupra proiectului prezentat.

Sinopsisul proiectului va fi redactat atât în română cât și în engleză. Ca dimensiunea recomandată aceasta secțiune va avea maxim 200 de cuvinte pentru fiecare variantă. Împreună, ambele variante se vor încadra într-o singură pagină.

Potrivit CDC [1] [2], 36,8% dintre adulții din SUA nu dorm suficient, iar 25,3% nu fac suficientă mișcare.

Folosind senzori, persoanele care suferă de aceste probleme își pot îmbunătăți viața cu ajutorul IA.

Această lucrare propune o metodă de analiză AI care, în primul rând, analizează comportamentul actual utilizând senzorii noștri IoT și apoi, utilizând modelul STC-NLSTMNet, un model nou care utilizează o convoluție spațio-temporală cu LSTM imbricat (\*\*\*MA GANDEAM SA FOLOSESC DOAR BI-LSTM, BI-LSTM se refera ca in loc ca sa circule intr-o singura directie secventiala, va circula in ambele directii si inainte si inapoi, adica de la inceput spre sfarsit si de la sfarsit catre inceput, permitand o capturare mai buna a informatiei), îl clasifică ca unul dintre cele 6 comportamente (mers, culcat, așezat, alergat, în picioare, căzut). [3]

După identificarea comportamentului, în a doua etapă, sistemul analizează datele colectate de la senzori, pe baza comportamentului trecut, și încearcă să facă mediul domestic să descurajeze, să încurajeze, să automatizeze sau să recompenseze un anumit comportament cu ajutorul LSTM. Exemple de astfel de comportamente includ reamintirea de a fi activ după o perioadă de inactivitate de peste 6 ore și optimizarea programului de somn prin închiderea jaluzelelor și oprirea dispozitivelor electronice.

# Abstract

The abstract has an introductory role and should engulf both a brief description of the issue at hand, as well as an overview of the obtained results and conclusions. The abstract should be formulated such that even somebody that is unfamiliar with the projects’ domain can grasp the objectives of the thesis while, at the same time, retaining a specificity level offering a bird’s eye view of the project.

The projects’ abstract will be elaborated in both Romanian and English. The recommended size for this section is limited to 200 words for each version. Together, both versions will fit in one page.

-short description of the approached problem

-short enumeration of the results and conclusions

-a short presentation about the project

(maximum 200 words)

Version 1

By 2050, the number of people with diabetes and elderly people will increase twofold, and they will become a significant portion of the world population.

Bearing this in mind, many within the AAL domain have emphasized the importance of utilizing modern technology to make the lives of these individuals significantly safer and more enjoyable.

Most research papers within the subject area have proposed utilizing IoT sensors such as motion, temperature, humidity sensors, etc., and time to prevent a fatal event from happening or remind a person to take a pill. But a significant problem that many researchers do not emphasize is that this technology could be used to optimize the lives of the general population, most of whom suffer from sleep problems and a sedentary lifestyle that significantly makes their lives less healthy and productive.

There will be presented an AI analysis method that, firstly, will analyze the current behavior by utilizing our IoT sensors and then, utilizing the STC-NLSTMNet model (highlight it more, explain it more)(I WAS THINKING OF USING JUST BI-LSTM model), will be classified into a list of 4-5 behaviors (sleeping, waking, inactive, active).

Upon identifying the behavior, in the second stage, we try to look at our data collected from sensors, and based on past behavior using LTSM, try to make the home environment mitigate, encourage, or reward a certain behavior. A couple of examples of such behaviors are: a reminder to be active after being inactive for more than 6 hours; optimize their sleep schedule by closing the blinds and electronic devices. In addition to this, we are trying to automate menial tasks such as turning the TV on at a certain time when it is usually watched.

According to the CDC [1] [2], 36.8% of US adults do not get the recommended amount of sleep, while 25% do not get the recommended amount of physical activity.

By utilising sensors, people who suffer from these types of problems could optimise their lives with the help of AI.

This work proposes an AI analysis method that, firstly, analyzes the current behavior by utilizing our IoT sensors and then, utilizing the STC-NLSTMNet model (I WAS THINKING OF JUST USING BI-LSTM model that unlike the traditional model, it can sequentially process information for both backward and also forward, from start to end, and also, from end to start, allowing the model to capture more information), a novel model that utilizes a spatiotemporal convolution with nested LSTM, classifies it as one of the 6 behaviors (walking, lying down, sitting down, running, standing up, falling). [3]

Upon identifying the behaviour, in the second stage, the system analyses the data collected from sensors, based on past behaviour, tries to make the home environment discourage, encourage, automate, or reward a certain behaviour with the help of LSTM. Examples of such behaviours include being reminded to be active after being inactive for more than 6 hours and optimising their sleep schedule by closing the blinds and turning off electronic devices.

# Mulțumiri

(opțional) Aici puteți introduce o secțiunea specială de mulțumiri / acknowledgments.

# Introducere

Parametrii de formatare recomandați pentru lucrare:

● Font recomandat: Calibri; Dimensiune font: 12;

● Spațiere între linii: 1,15; Spațiere după paragraf: 8pt;

● Stil: Justified;

● Dimensiune pagină: A4; Margini: 2,54cm/ 2,54cm/ 2,54cm/ 2,54cm;

● Heading1: Calibri, 14, bold, all caps;

● Heading2: Calibri, 14, bold;

● Heading3: Calibri, 12.

1. Font pentru formule: Cambria Math, 12.  
     
   În cadrul introducerii, este necesară abordarea următoarelor puncte care reprezintă de fapt familiarizarea cititorului (comisia, alți colegi sau experți în domeniu) cu tema proiectului, soluția propusa și cuprinsul/structura lucrării. Deși introducerea poate conține și unele elemente mai generale, se recomandă păstrarea unui limbaj tehnic, specific audienței care va citi lucrarea.  
     
   În cadrul capitolelor următoare, veți regăsi o serie notații de forma [Dezvoltare de produs], [Cercetare]. Acest tip de formatare este utilizat exclusiv în acest template pentru a marca sfaturi și cerințe specifice pentru lucrări de diploma cu specific diferit. În pregătirea documentului vostru, nu veți utiliza aceste marcaje.  
     
   Elementele pe care trebuie să le abordați în introducere sunt descrise în cadrul subcapitolelor de mai jos.

## 1.1 Context

O scurtă introducere a proiectului, motivație, explicație de ce este relevant domeniul proiectului.

With the advancement and ever-bigger presence of technology, there has been an increase in smart homes and IoT devices. This general trend is emphasized by Statista, which predicts that by 2030, the number of connected IoT devices will grow to 31.2 billion from 19.8 billion in 2025 [4]. Within the domain of smart homes, a new domain has emerged, the domain of AAL, Ambient Assisted Living, whose main use is to help people with vulnerabilities, such as elderly people and people with diabetes. However, there is a growing need to address the proper needs of the general population, which faces problems such as inadequate sleep and sedentary lifestyles, and to reduce time spent on trivial tasks, which could be spent on more productive activities. These problems can be solved by establishing a healthy routine, a set of actions that are done every day, which takes into consideration the needs of the user.

The main motivation for developing this project was optimising as best as possible the routine of a person, based on previous habits, either through automation or helping that person improve their habits gradually. Human willpower is finite, and it eventually runs out. A significant factor determining certain behaviours is the environment, which can be customised with the help of AI and IoT to improve one's behaviour. An experiment that proved the importance of the environment is the Pavlovian dog experiment, in which a neutral stimulus initially becomes associated with reward over time. Within this project, the neutral stimulus is represented by our inputs from CSI (Channel State Information) sensors, which are used to detect human activity using Wi-Fi signals. Over time, these signals are associated with a certain behaviour.

## 1.2 Problema

Care este problema pe care proiectul o va rezolva.

The main problem tackled in this project is helping the user improve their habits, such as sleeping earlier. This is done by taking into consideration the user’s previous habits and making the adjustment in a gradual way for a seamless experience.

Another problem it aims to solve is to use electronic devices and IoT devices without needing user intervention, making it easier for the homeowner to concentrate on the important tasks and reducing the time spent on minor tasks such as household and family care. Examples of such activities include cooking, household cleaning, clothes washing and ironing, scheduling, shopping, etc. In EU countries, household and family care (excluding childcare) takes between 35 minutes and 1 hour and 17 minutes, according to Eurostat [5]. And most of these activities can be automated, and in addition to saving time, they will reduce the mental toll on the user by being able to focus better on their work or time spent indoors.

A gap in the market is that most existing solutions are either manual, which may distract the user from doing their task, or there are moments when the user forgets about setting the IoT devices, which can have a disruptive effect on their routine and affect their consistency. Another gap is the fact that most existing AAL solutions focus on the elderly or people with vulnerabilities, such as people with diabetes; there are not many AAL solutions that cater to the general population. This project focuses on the general population.

## 1.3 Objective

Care sunt obiectivele proiectului/soluției/abordării/ideii; Ce creșteri sau evoluții determină rezolvarea proiectului.

The objective of this project is to develop a system that can (1) classify the behaviour as one of the 6 behaviours (walking, lying down, sitting down, running, standing up, falling) based on CSI sensor data; (2) analyse the behaviour, whether it is positive, negative, or neutral. Then, if a neutral behaviour is detected, the system will automate the behaviour in the case of doing simple tasks; (3) if it is not one, it will optimise it by analysing past events of a certain behaviour using LSTM.

(I should move this section after the solutions section.)

The classification is being done by analysing past events, where their behaviours are encountered. And based on the similarity of each class of behaviour, the classification is made.

After finding the behaviour, it is analysed and determined whether it has a negative or positive effect on your productivity and mental being (e.g., sleeping late or not sleeping enough, for negative; or being active, for positive; or cooking food, for neutral). If the behaviour is neutral, the system will automate that task, based on patterns, whether you are doing a certain behaviour like sitting on the couch in the morning, based on past behaviour, you used to watch TV, the TV turns on automatically.

Now that behaviour has been analysed, based on previous data where that behaviour was recorded, the system will help in optimising that behaviour by making the environment around it help in facilitating a good behaviour or preventing bad behaviour.

## 1.4 Soluția propusă

Descrierea pe scurt a soluției implementate; ce abordare este propusă (nu detalierea utilitarelor și a tehnologiilor, ci abordarea și ideea propusă de către autor).

- i will describe the conceptual model right now

In the solution for this problem, during the first stage, the classification is done by analysing past events, where their behaviours are encountered. And based on the similarity of each class of behaviour, the classification is made with the help of (STC-NLSTMNet, a spatiotemporal convolution nested) Bi-LSTM model, a two-layered LSTM model, which is useful for tracking motion without using a vision-based tracking system. It is used as the architecture.

The project uses preprocessed datasets such as StanWIFI and a Multi-environment dataset.

The STC-NLSTMNet consists of: DS-Conv used for extracting the spatial features, then the FAM (Feature Attention Module) is used for extracting the most relevant features, NLSTM [nested LSTM with inner layer and outer layer(s)], which is used to extract its temporal features, and is more precise than other LSTM architectural models, and TDFC (time-delayed feedback control) to extract the output characteristics from multiple time steps of NLSTM.

During the next step, the model will do activity recognition using GAP (Global Average Pooling), which helps in reducing spatial dimension while retaining information; Fully Connected Layer (Dense Layer), where every neuron is connected to every node in the previous and next layer; and SoftMax, which helps convert output scores(logits) into probabilities. (2)

After the activity recognition, it will be analysed and determined whether it has a negative or positive effect on your productivity and mental being (e.g., sleeping late or not sleeping enough, for negative; or being active, for positive; or cooking food, for neutral. If the behaviour is neutral, the system will automate that task based on patterns. With the usage of the LSTM learning process, it is either able to automate a certain process, such as turning the TV on, turning on the blinds, etc., or give a reminder, such as taking the pills, thus making the environment around it facilitate good behaviour or prevent bad behaviour.

## Rezultatele obținute

Descriere pe scurt a rezultatelor obținute, eventual de ce acestea sunt importante față de alte soluții sau studii

**1.6** **Structura lucrării**

Un paragraf în care fiecare dintre secțiunile următoare este prezentată în 1-2 fraze, punând accentul pe elementele cele mai semnificative din fiecare secțiune.

Chapter 1 there is a short introduction into the diploma project and its background, problems addressed, objectives and proposed solution.

Chapter 2 presents the existing market demands by surverying people and presents existing research papers and technologies that were previously used within the domain of Ambient Assisted Living that have some sort of connection to my work.

Chapters 3, 4 present the proposed implementation to solve the problem above, Chapter 3 presenting the conceptual work part and Chapter 4 presents the work in more detail.

# Analiza și specificarea cerințelor

[Dezvoltare de produs] Acest capitol va analiza cerințele produsului din prisma potențialilor clienți și a scenariilor de utilizare preconizate, urmând a fi generată o lista de funcționalități.

[Cercetare] Acest capitol va introduce motivația realizării proiectului propus.

Dacă proiectul de licență face parte dintr-un proiect mai amplu (de exemplu un proiect complex, la care lucrează 2 studenți (ex: 1 student la front-end ul aplicației, 1 student la backend-ul aplicației), în acest capitol va fi explicat pe scurt ansamblul proiectului și ce parte din proiect este adresată de lucrarea propusă.

Criterii pentru calificativul Nesatisfăcător:

* [Dezvoltare de produs] Cerințele sunt imaginate de student pe baza unei analize a pieței;
* [Cercetare] Nu se oferă o motivație validă.

Criterii pentru calificativul *Satisfăcător*:

* [Dezvoltare de produs] Există un interviu, un client, analiza cerințelor este elaborată pe baza interviului;
* [Cercetare] Motivația este doar personală.

Criterii pentru calificativul *Bine*:

* [Dezvoltare de produs] Proces iterativ pe baza unor interviuri cu mai mulți clienți, dezvoltare MVP, reevaluare cerințe;
* [Cercetare] Motivația este legată de o necesitate științifică / tehnică explicită.

Main motivation: desire to make the most of our current data, optimise our lives (to enjoy our lives more), unify this data to make this possible, and integrate this project into something wider (maybe integrate within a smarter city)

-Talk more about the proposed system, and the relationship between humans and the environment Xiaopeng Jia, Jun Chenga, Wei Fenga, Dapeng Tao

- integrate Pavlovian conditioning, human efficiency, and an increase in happiness

In our current day and age, we are surrounded by smart devices that track our data, such as WIFI devices, IoT devices, etc. Most of the data is unutilized, and currently, most of these devices, instead of helping us, are distracting a significant amount of our time. It would be helpful if this data could be unified to make our lives more productive. With the growing number of elderly and individuals who suffer from chronic illnesses, and with the increase in people who suffer from tech addiction (**over 43% of Americans admit feeling addicted to their phones** [6]), this is more imperative than ever.

This project, is a starting point in achieving this feat, in this project we plan to utilize the CSI sensors to recognize behaviors, which offers a better method of behavior recognition compared to video cameras in terms of privacy, cost of equipment and range (in video cameras, the behavior of the subject could not be correctly interpreted due to being behind an obstacle or the camera angle does not recognize the behavior properly), in essence, this project represent creating a complementary relationship between human and their environment, merge data with automation and behavioral correction.

Inspired by Pavlovian conditioning, the system also explores behaviour reinforcement through intervention and feedback.

(This project focuses on the decision-making and reasoning module of the larger architecture, using AI to detect patterns (unsupervised) and predict or classify behaviours (supervised). )

(mention also human efficiency and increase in happiness)

**2.1 Scenarii de utilizare**

- sistemul intereactiune dintre utilizator si mediul lor casnic

- sa prezint ce fac cu dispotizitele

- doua scenarii in care datele colectate sunt procesate pt a detecta comportamente

- declansa actiuni si oferi feedback

- scenarii functionala si non-functionale

The proposed system envisions a concept for intelligent, automated, and personalised interaction between the user and their own environment, based on a diverse set of CSI WIFI sensors. In the following section, we will present two scenarios that exemplify and enhance understanding of how this system works by illustrating the process of collecting data for processing, detecting behaviour, triggering action, and offering adaptive feedback or automating repetitive behaviour. Each scenario has a learning and inference phase.

In the training phase, which is essential for learning when to activate this automatic behaviour, the system will have to follow these steps:

1. Collect past CSI data – gather WIFI signals over days/weeks, label them with action (sitting, standing, lying down, etc.), context (time of the day, location), and what action followed on, outcome (turning the TV, sleeping in the bed)
2. Preprocess data – clean CSI, extract features
3. Detect/Label behaviour type:

* Automation: short-term, which triggers instantly (such as turning on the TV, cooking a recipe)
* Optimisation: long-term habits, which can be separated into good (exercising) and bad behaviours, such as sleeping late. Each action is rewarded (e.g., we receive a notification that we have a 100-day streak) or penalised, in our case, is restricted, so that the behaviour is optimised.

4. Train LSTM Models: Learn patterns from CSI + time – one model for automation and one for optimisation

5. Validate and save models

In the inference phase, we detect our behaviour and take an appropriate action. We will present the generalised steps:

1. Activity detection – we are detecting current action based on the CSI sensors (e.g., sitting, lying down)
2. Context gathering – time of the day (morning, 10 AM/PM, etc.)
3. Run LSTM inference: input (time, CSI features), output (predicted behaviour “TV on” with 72% probability or restrict time before a specific hour (TODO IMPORTANT TO FIND HOW TO FIND THAT HOUR!!!!!!)
4. Decision: which type of behaviour is it part of – either part of the automated (neutral behaviours) or the optimised (negative, positive behaviours), then branch into that specific type.
5. Action and feedback loop:

- for automation:

* If the automation was wrong (e.g., turned off the TV), the score is lower for the prediction
* If the automation was correct, the score is improved for the prediction

- for optimisation:

* If it is a bad behaviour, we restrict the action until we reach the desired target.
* If it is good, implement a streak feature, and once a day, the user gets a notification that it has a “X-day” streak

Scenario 1: Turning on the TV automatically

A user, most of the time, when he sits in the coach in the morning, he usually turns on the TV. Based on past behaviour during the morning, using LSTM, and based on the CSI Wi-Fi sensors that detect that he is lying down on an object, we infer that he wants to watch TV during this time of the day.

In this scenario, the following steps are done:

1. Activity Detection – CSI sensors detecting the sitting activity
2. Context gathering – the time of the day is 9 AM or morning
3. Inference – TV is detected based on previous data, with a high probability
4. Decision – Classified as automated behaviour, based on this action (VERY IMPORTANT: IT IS IMPORTANT TO FIND OUT HOW TO DISTINGUISH BETWEEN AUTOMATED AND OPTIMIZED BEHAVIOR)
5. Feedback loop – if the TV is turned off, decrease the score for this prediction; otherwise, increase it.

Scenario 2: Optimising sleep schedule

For this scenario, it is important to determine the ideal bedtime; without that, we cannot proceed forward (HOW TO DO IT???)

In this scenario, based on past data, we determine that the user has a bedtime that is beyond the ideal sleep time, so we classify it as bad behaviour. To rectify it, we introduce restrictions such as turning off the electricity and internet until it manages to sleep within the ideal bedtime or earlier. If the user manages to do this, the system will start to reward him by introducing a streak feature, where each day, he will be notified that he has an X-day streak.

In this scenario, the following steps are done:

1. Activity Detection – CSI sensors detecting the lying activity or any activity in the house
2. Context gathering – the time of the day beyond the ideal time
3. Inference – LSTM predicts late-night sleep pattern
4. Decision – Classified as optimisation (bad behaviour)
5. Feedback loop – if it is bad behaviour, we restrict the user; if it is good behaviour, we reward the user

**2.2 Functional and non-functional requirements**

**Functional (what it must do):**

* Automatic detection of behaviour based on CSI Wi-Fi sensors using LSTM.
* Automating certain trivial(neutral) actions, such as turning on the TV
* Give notifications if the behaviour is positive for automatic behaviours and restrict in case of negative behaviours

**Non-functional:**

* Respects the anonymity of the user using a non-intrusive HAR method
* It can function even offline
* Robustness – even if some data is noisy (MAYBE DELETE THIS or add another thing)

# Studiu de piață / Abordări existente

[Dezvoltare de produs] Ce soluții similare există pe piață? Care sunt limitările lor / pentru ce cazuri de utilizare sau pentru ce tip de clienți produsele existente pe piață nu răspund cerințelor? Care sunt indicatorii pe baza cărora sunt evaluate aceste produse, de către potențiali clienți, și unde sunt lipsurile/ care este oportunitatea generată de lipsurile acestea?

[Cercetare] Metode existente (sau „State of the Art“) se referă, de regulă, la nivelul curent de dezvoltare: care este starea curentă a domeniului, unde ne găsim, care este contextul. Care sunt soluțiile actuale prezente în literatura de specialitate și care sunt limitările lor? Ce direcții de explorare sunt recomandate în literatura de specialitate? Literatura de specialitate se referă la articole științifice recente, publicate în reviste cu factor de impact mare, sau în volumele unor conferințe de top, sau în cărți.

[Ambele] În încheierea acestui capitol se dorește descrierea tehnologiilor folosite în lucrare, cu alternative și cu argumente convingătoare calitative și cantitative.

Criterii pentru calificativul *Nesatisfăcător*:

* [Dezvoltare de produs] Sunt analizate superficial câteva produse de pe piață;
* [Cercetare] analiza literaturii limitată la grupuri de cercetare din România;
* [Ambele] Sunt descrise tehnologiile folosite în lucrare.

Criterii pentru calificativul *Satisfăcător*:

* [Dezvoltare de produs] Există un interviu, un client, analiza cerințelor este elaborată pe baza interviului.
* [Cercetare] analiza literaturii de specialitate din lume, fără poziționarea precisă a lucrării în peisajului domeniului studiat;
* [Ambele] Sunt descrise câteva tehnologii alternative pentru fiecare din tehnologiile folosite în lucrare. Există o argumentare referitoare la alegere.

Criterii pentru calificativul *Bine*:

* [Dezvoltare de produs] Proces iterativ pe baza unor interviuri cu mai mulți clienți, dezvoltare MVP, reevaluare cerințe;
* [Cercetare] analiza literaturii de specialitate din lume, cu poziționarea precisă a lucrării în peisajul actual al domeniului studiat;
* [Ambele] Sunt descrise tehnologii alternative. Sunt analizate cantitativ și calitativ, folosite benchmarkuri și teste efectuate de student. Analiza este rezumată prin tabele și grafice.

Within my work, we will cover three main domains: HAR (Human Activity Recognition), SHA (Smart Home Automation), and AAL (Ambient Assisted Living). The topic of HAR (Human Activity Recognition) has been deeply researched, and there are several relevant works related to this topic. Furthermore, the same can be said about Smart Home Automation, which is an emerging field. In Ambient Assisted Living, there are numerous works that focus on the topic.

Most of the current literature focuses on these domains separately, without combining them, so this work aims to address a significant gap in the literature and practical applications by combining all these topics, which complement each other.

This combination is important because HAR detects activities but does not optimize the environment; SHA helps with the automation but cannot develop a deeper understanding of habits; AAL is mainly focused on helping vulnerable groups such as the elderly and people who suffer from chronic conditions (e.g., diabetics), while not focusing on the general population, optimizing behavior, and automating tasks. Therefore, a unified approach is required.

**Existing approaches in literature (State of the art)**

For HAR, there are multiple approaches in the literature to detect human activity.

A classical method is the vision-based HAR, which requires a visual input to capture the human body. Relevant works in this area include Cheng et al. [7], Vemulapalli et al. [7], and Xia et al. [8], all of which convert the image of the human body into a 3D representation, in which vectorial operations are applied. Each of them had different approaches to the 3D representation: Xia et al. [8] used Histograms of 3D joint locations; Cheng et al. [7, 7] represented 3D points into a set of body parts, and Vemulapalli et al. [7] modelled the 3D points as curves using Lie group and converted them into Lie algebraic representation. As for models, Xia et al. [8] used HMM (Hidden Markov Models) in helping to classify the data, while Vemulapalli et al. [7] used SVM and Fourier analysis to classify it. However, as evidenced by Md Shafiqul Islam et al. [3], vision-based HAR systems invade users’ privacy and fail to detect action behind an obstacle. (POATE SA PREZINT SI ACCURACY-UL LA UNA???)

A non-intrusive HAR approach is the radar-based HAR. Important works in the area include Karayaneva et al. [9], which uses Doppler radar signals to recognize daily activities for elderly care homes using an unsupervised framework; Franceschini et al. [10] trained a CNN (convolutional neural network) on Doppler radar signals for recognition of hand gestures, reaching an accuracy of 97% on experimental data; Kim et al. [11] use DL (Deep learning) for the Doppler radar, “combining a range-time-Doppler (RTD) map and a range-distributed-convolutional neural network (RD-CNN)”. The weak point of this approach, as mentioned by Md Shafiqul Islam et al. [3], is that the procedure of labelling and collecting a large amount of radar data points requires a significant amount of people and money, because the available amount of radar data is limited, being behind a real-time scenario.

I WILL WRITE MORE ABOUT THE DATABASES, MAYBE NOT USE ROBOCASA.

Bullet point CSI

One more non-intrusive HAR technology that can be extended to other datasets is the Wi-Fi-based HAR. [3] This technology is separated into two types of signals: RSSI (Received Signal Strength Indicator) and CSI (Channel State Information). Even though RSSI WIFI-based HAR produces 80% accuracy, a weak side of RSSI is that the signal becomes weaker as the subject gets further away from the transmitter. In addition to that, it produces only coarse information about channel fluctuations, multipath effects, and noise frequency influences it. [3]

A key advantage of CSI WIFI Technology is that it respects privacy and is quite versatile in terms of data, and can perform well with obstacles. In addition to that, it is reliable, depending just on a Wi-Fi router, which is the transmitter, and a laptop, which is the receiver. [12]

Md Shafiqul Islam et al. [3] used the STC-NLSTMNet, which is a state-of-the-art model that managed to produce a general accuracy for LOS (line of sight) of 98,2% and 96.65 [12], for Office Room and Hall Room, respectively. Furthermore, it managed to have an accuracy of 94.68% in an NLOS (non-line of sight) environment. The architecture, STC-NLSTM, combines both spatial and temporal features; for the former, it uses a DS-Conv block, and then the most relevant features are extracted with the help of FAM (Feature Attention Module), while for the latter, NLTSM is used to explore the hidden temporal features, which contributes in having a high accuracy for the recognition of human activity. The model consists of a spatial-temporal feature extraction (STFE) and recognition. The STFE section has one 2D CNN, three DS-CONV blocks, two FAM, and an NLTSM, [which enhances the depth of LSTM through nesting, being able to select and use information from CSI signals in a more efficient manner. [3] (Maybe add this: The internal memory cells can retain and process long-term features of CSI signals, which are complemented with external memory cells that are responsible for data selection and processing.) (aici cam s-ar considera plagiat, ca nu stiu daca am luat mot—mot sau nu]. This differs massively from stacked LSTM, in which the output of the previous layer is used as input for the subsequent layer. The second paper by Zhang et al. [12] uses Bi-LSTM, which is a well-established model (MAYBE INCLUDE OTHER PAPERS) in the literature, opting for a more practical approach. Bi-LTSM is an LTSM that processes sequential information in both forward and backward directions, being able to capture the past and future contexts simultaneously of the input sequence. Traditionally, the data is processed only in one direction. It consists of two LSTM layers: one backwards and one forward. Zhang et al. compare BI-LSTM to other methods such as SVM (Support Vector Machine), KNN (K-Nearest Neighbour), DT (Decision Tree), RF (Random Forest), GRU (Gated Recurrent Unit), and LSTM, where each of them is used as a classifier. BI-LSTM performed the best in accuracy, precision, recall, and F1, all above 98. In regard to accuracy, the BI-LSTM scored 98.7%. A weak point in this literature was that it used only LOS(Line of Sight), and not NLOS, when testing the accuracy of the method. We plan to implement BI-LSTM, as it is more practical and feasible to implement this method.

**Limitations of Current Research Solutions:**

Within these sensor types, there are currently several limitations with each of them.

* For Vision-based HAR, even though it has high accuracy, there are privacy concerns, and it has a problem with recognising movements if there is an obstacle in front of the subject that is obstructing the FoV (field of view) for the imaging system.
* For Radar-based HAR, it is accurate and manages to not be privacy intrusive, but collecting datasets for it can be quite costly, due to the collection being heavy
* For CSI-based HAR, it is accurate, not privacy intrusive, and datasets can be accessible and scalable, but the literature surrounding CSI-based HAR is currently only single-user

**Recommended Exploration Directions:**

The biggest limitation, among these research solutions, is the fact that they are meant only for a single user for CSI HAR, and implementations that can adjust to multiple people are scarce. A recommended exploration direction is an implementation of a multi-user system that integrates CSI HAR. Another big minus among those is that the number of actions that are tested is quite limited, usually being fewer than 10 actions that are used in the datasets, and thus few actions that are being recognized; even though in real-time every day, the number of activities done by the human being surpass this number by a lot, but currently, it is hard to track and quantify each movements. Having a dataset that manages to effectively capture a plethora of motions could help in improving smart home automation and optimising more tasks. Furthermore, even though there have been studies such as those conducted by Md Shafiqul Islam et al. [3], most other studies do not handle the case in which the subject is obstructed by an obstacle, such as in NLOS (non-line of sight), especially for the CSI Wi-Fi HAR, where this was pointed out as an potential advantage of this method. If there were a significant number of studies that treated this subject more clearly, it would help in confirming the findings of Md Shafiqul Islam et al. [3] or in refuting their findings.

A potential gap that our paper manages to fill is the fact that currently, there aren’t many research papers that integrate HAR (Human Activity Recognition) with Smart Home Automation, and we are referring specifically to habit optimisation, not to just the detection of habits. Most literature papers, such as Fahad et al. [13], have the topic of Human Activity Recognition in a Smart Home environment, but it is not integrated with SMA (Smart Home Automation), and tackle issues related to vulnerable groups such as the elderly and people with chronic illnesses, instead of approaching the general population. In this paper, they used HAR to track anomalies with the elderly and to assess their physical and cognitive impairments. This can also be remarked in the paper of Susantok et al. [14], where we see that issue of Smart Home Automation is related only to a more efficient use of energy, and automation helps in optimizing the energy use only where it is necessary, but it works such as these are connected to the Human Activity Recognition, as we have been pointing out in the beginning of these section.

### **Proposed Technologies and Alternatives**

In my paper, we choose to implement a Wi-Fi CSI + BI-LSTM for HAR, which is feasible, easy to replicate, and has strong accuracy. In the future, we plan to upgrade to STC-NLSTMMNet, which is an advanced, state-of-the-art model with higher complexity that handles even NLOS (non-line-of-sight) cases. This is for the HAR, this model has been implemented by Zhang et al. [12], and for the Smart Automation Part, we decided to choose the model made by Susantok et al. [14], where it was implemented a model that uses LTSM + Automatic Control, for the automation of the household tasks, but adapted to our own use case, for automation of household items when the detected behavior is a simple one such as turning the TV, while at the same time, optimize the action, by restrict it, if it negative, or incentivizing through a reward system, if it positive

This ensures a seamless integration into our system.

The model presented by Md Shafiqul Islam et al. [3] (STC-NLSTM):

* Consists of a spatial-temporal feature extraction (STFE) and recognition. The STFE section has one 2D CNN, three DS-CONV blocks, two FAM, and an NLSTM.
* 2D CNN and DS-Conv blocks, two FAM, and NLSTM. 2D CNN and DS-Conv blocks extract the spatial features from CSI, and fam helps to focus on the most significant spatial features.
* NLSTM enhances the depth of LSTM through nesting to select and use information from CSI signals in a more efficient manner. The nesting involves selecting and using information from CSI signals more efficiently. The internal memory cells can retain and process long-term features of CSI signals, while the external memory cells are responsible for data selection and processing.
* NLSTM can extract long-term temporal features of CSI signals more stably and effectively. A time-distributed fully connected (TDFC) layer is utilised to acquire the output characteristics of the NLTSM layer at each of its time steps. This TDFC layer uses the outputs of all time steps of the NLSTM rather than only using the most recent time step’s output. On the contrary, in the recognition section, GAP, FC, and softmax layers ARE used. [3] (am luat mot-a-mot aici, nu stiu daca este bine).
* In a stacked LSTM, the output of the previous layer is used as input for the subsequent layer.

In the paper presented by Zhang et al. [12], BI-LSTM is used, which is an LSTM that processes sequential information in both forward and backward directions, being able to capture the past and future contexts simultaneously of the input sequence. Traditionally, the data is processed only in one direction. It consists of two LSTM layers: one backwards and one forward.

## Indicații formatare figuri

Figurile utilizate în document vor fi centrate și numerotate (de exemplu Figura 1).

Orice figură ce nu este realizată de către autorul lucrării va fi în mod obligatoriu citată fie la final (de exemplu Figura 2 este preluată din documentul [1]), fie cel puțin într-o notă de subsol (a se vedea Figura 2). Orice figură ce depășește ca dimensiune 50% dintr-o pagină, va fi mutată la anexe. Toate figurile din cadrul tezei vor fi referite în text. Exemplu: Figura 1 prezintă o schemă de principiu pentru un amplificator inversor cu AO.

A screenshot of a computer

AI-generated content may be incorrect.

A diagram of a diagram

AI-generated content may be incorrect.

This part is made with ChatGPT

# Studiu de piață / Abordări existente

[Dezvoltare de produs] Ce soluții similare există pe piață? Care sunt limitările lor / pentru ce cazuri de utilizare sau pentru ce tip de clienți produsele existente pe piață nu răspund cerințelor? Care sunt indicatorii pe baza cărora sunt evaluate aceste produse, de către potențiali clienți, și unde sunt lipsurile/ care este oportunitatea generată de lipsurile acestea?

[Cercetare] Metode existente (sau „State of the Art“) se referă, de regulă, la nivelul curent de dezvoltare: care este starea curentă a domeniului, unde ne găsim, care este contextul. Care sunt soluțiile actuale prezente în literatura de specialitate și care sunt limitările lor? Ce direcții de explorare sunt recomandate în literatura de specialitate? Literatura de specialitate se referă la articole științifice recente, publicate în reviste cu factor de impact mare, sau în volumele unor conferințe de top, sau în cărți.

[Ambele] În încheierea acestui capitol se dorește descrierea tehnologiilor folosite în lucrare, cu alternative și cu argumente convingătoare calitative și cantitative.

Criterii pentru calificativul *Nesatisfăcător*:

* [Dezvoltare de produs] Sunt analizate superficial câteva produse de pe piață;
* [Cercetare] analiza literaturii limitată la grupuri de cercetare din România;
* [Ambele] Sunt descrise tehnologiile folosite în lucrare.

Criterii pentru calificativul *Satisfăcător*:

* [Dezvoltare de produs] Există un interviu, un client, analiza cerințelor este elaborată pe baza interviului.
* [Cercetare] analiza literaturii de specialitate din lume, fără poziționarea precisă a lucrării în peisajului domeniului studiat;
* [Ambele] Sunt descrise câteva tehnologii alternative pentru fiecare din tehnologiile folosite în lucrare. Există o argumentare referitoare la alegere.

Criterii pentru calificativul *Bine*:

* [Dezvoltare de produs] Proces iterativ pe baza unor interviuri cu mai mulți clienți, dezvoltare MVP, reevaluare cerințe;
* [Cercetare] analiza literaturii de specialitate din lume, cu poziționarea precisă a lucrării în peisajul actual al domeniului studiat;
* [Ambele] Sunt descrise tehnologii alternative. Sunt analizate cantitativ și calitativ, folosite benchmarkuri și teste efectuate de student. Analiza este rezumată prin tabele și grafice.

(mention about recent advances in ai technology in the field of smart homes, such as smart thermometers and such smart schedulers etc).

## Market Study / Existing Approaches: Analysis of Current Solutions and Research Status in AI-Powered Smart Home Systems

This chapter analyzes the current landscape of Artificial Intelligence (AI) and Machine Learning (ML) solutions in smart home systems (SHS), highlighting both commercial products and advancements in academic literature. The limitations of existing approaches and opportunities for innovation are discussed, as well as the technologies proposed in this work, along with the arguments supporting them.

### **Similar Commercial Solutions and Their Limitations**

In the market, smart home systems have evolved significantly due to advances in AI and cloud computing, with notable examples such as smart thermostats (e.g., Google Nest, Ecobee) and scheduling systems for lighting, HVAC, and appliances. These devices are capable of learning from user feedback and adaptively adjusting their settings to human preferences.

Limitations and Evaluation Criteria:

Most of these solutions operate based on simple "if-this-then-that" (IFTTT) rules or static schedules, which limits their adaptability and deep understanding of human behavior. There is an inefficiency in the centralized management of the large volume of data generated by sensors and wearable devices (smartwatches, smart rings, fitness trackers, etc.), data that is not managed efficiently in a single space. This gap represents a major opportunity for the development of AI solutions that can efficiently manage and utilize this data to simplify and streamline the user's life.

In addition to the lack of adaptability, existing products can lead to unintended changes in user behavior if models are generalized incorrectly. Current systems require adequate training and testing on a wide range of users to fully understand their potential impacts and implications. The opportunity lies in creating a system that provides personalized commands and feedback, based on local data analysis to minimize cybersecurity risks and improve the efficiency of daily tasks, such as energy management or optimizing ambient temperature based on sleep patterns.

### **Existing Methods in Research ("State of the Art")**

Academic research has advanced towards smart home systems based on reinforcement learning (RL). For example, the study by Suman et al. (IEEE TAI 2022) used Q-learning and hierarchical reinforcement learning (HRL) to model the autonomous adjustment of temperature and humidity by smart homes, based on observed human behavior (rest, leisure, physical activity).

Other research directions include:

* The use of Double DQN for ventilation control and maintaining air quality.
* Deep neural networks for predicting energy consumption patterns.
* The application of Hidden Markov Models (HMM) for action recognition and detecting user activity patterns.
* The use of Random Forests for modeling time-series sensor data.
* The integration of sensors with contextual learning, although still facing limitations.
* In Ambient Assisted Living (AAL), a range of ML algorithms have been investigated, including Deep Neural Networks (DNNs), Support Vector Machines (SVM), Decision Trees, Convolutional Neural Networks (CNNs), Natural Language Processing (NLP), Federated Learning, Gated Recurrent Units (GRU), Logistic Regression, XGBoost, Generative Adversarial Networks (GANs), and Transformers.

Limitations of Current Research Solutions:

Despite these efforts, significant gaps remain in:

* **Adapting to multiple users:** Systems struggle to adapt to the conflicting preferences of multiple users.
* **Generalization across different environments:** The ability of models to generalize across diverse environments remains a challenge.
* **Feedback loops for continuous learning:** The integration of feedback loops for continuous learning is limited.
* **Interpretability and reactivity:** The interpretability and reactivity of technologies like HMM and Random Forests vary depending on the scenario.
* **Unintended behavioral changes:** Incorrectly generalized models can lead to unexpected changes in user behavior, such as frequent activity switching.
* **Privacy and ethics:** The implementation of AI technologies in AAL raises significant challenges related to data privacy management, ethical compliance, and user acceptance. Also, integrating real-time data from IoT devices and wearables is complex to manage and interpret.
* **Limited contextual awareness:** Sensor-based systems can detect movements but lack environmental context (e.g., whether a fall was caused by furniture obstacles).
* **Data noise and calibration issues:** Sensor readings are susceptible to errors, noise, and inaccuracies, requiring frequent recalibrations.
* **Limited IoT-ML integration:** The integration of IoT with ML-based health monitoring is often insufficient, suggesting an area for deeper research integration.

Recommended Exploration Directions:

The academic literature suggests the following directions for research:

* Developing systems capable of personalization for individual users, but which can scale to multi-user households.
* Ensuring long-term adaptation without requiring extensive re-training.
* Integrating behavioral correction or nudging mechanisms based on psychological models (e.g., Pavlovian conditioning).
* The need for interpretability in AI-driven decisions.
* Exploring the role of Generative AI (GenAI) in synthetic data generation and personalized conversational assistants.
* Addressing privacy and ethical issues to ensure the benefit and security of AAL technologies.
* Developing adaptable systems that can dynamically respond to the evolving needs of elderly individuals.

### **Proposed Technologies and Alternatives**

The project proposes a modular, AI-driven behavior recommendation engine, using a combination of unsupervised learning, DDQN (Double Deep Q-Network), and pattern analysis, to both identify and modify user behavior through adaptive interventions.

**Arguments for Technology Selection:**

* **DDQN vs. Q-learning:** DDQN was chosen over traditional Q-learning due to its improved convergence and stability.
* **CNN-LSTM Networks vs. Simple RNNs:** CNN-LSTM networks were preferred over simple recurrent neural networks (RNNs) due to their superior ability to capture spatio-temporal dependencies in sensor data.

A diagram of a diagram

AI-generated content may be incorrect.

# 

Introducere despre importanta modelarii comporatamentelor pentru sistemele smart

Prezentarea dispozitivelor utilizate

Corelari dispozitiv-comportament(de scris)

Legenda codurilor sensoriale (A-K/S)

Clasificarea comportamentelor in: pozitive, negative, neutre.

Observatii privind fiabilitatea corelarilor

# Soluția propusă

Capitolul conține o privire de ansamblu a soluției ce rezolvă problema, prin prezentarea structurii / arhitecturii acesteia. În funcție de tipul lucrării acest capitol poate conține diagrame (clase, distribuție, workflow, entitate-relație), demonstrații de corectitudine pentru algoritmii propuși de autor, abordări teoretice (modelare matematică), structura hardware, arhitectura aplicației.

Criterii pentru calificativul *Nesatisfăcător*:

* Descriere în limbaj natural.

Criterii pentru calificativul *Satisfăcător*:

* Descriere + diagrame de baze de date, workflow, clase, algoritmi.

Criterii pentru calificativul *Bine*:

* Descriere + diagrame de baze de date, workflow, clase, algoritmi + descrierea unui proces prin care s-a realizat arhitectura/structura soluției.

The proposed solution presents an intelligent, modular system designed to recognize user behavior patterns and autonomously automate repetitive actions through IoT devices. The system aims to reduce user effort in routine tasks, promote healthier habits, and ensure comfort and safety in a smart home environment.

The system consists of three core layers:

**1. Data Collection and Synchronization Layer** This component gathers real-time data from various smart home sensors and wearables: motion detectors, environmental sensors (temperature, humidity, light), appliance usage monitors (e.g., smart plugs), and location beacons. The data is cleaned, normalized, and temporally aligned for consistency.

**2. Behavior Recognition and Interpretation Layer** Two model types are used depending on behavior complexity:

* For **simple, isolated behaviors** (e.g., "sitting," "room is empty"), a **Convolutional Neural Network (CNN)** is used to classify individual sensor snapshots quickly.
* For **more complex sequences** (e.g., "preparing food," "getting ready for bed," "cleaning routine"), a **CNN-LSTM** architecture is deployed, combining spatial feature extraction with temporal pattern analysis.  
   These models are trained for **Human Activity Recognition (HAR)** and environmental state detection, enabling the system to infer routines and behavior patterns with high accuracy.

**3. Decision-Making and Automation Layer** Upon detecting a behavior, the system uses a **Double Deep Q-Network (DDQN)** to decide the optimal action, and **automatically executes that action via connected IoT devices**.

For example:

* When cooking is recognized, the system may activate a smart timer, turn on the exhaust fan, or start boiling water for a predefined simple dish (e.g., pasta).
* When screen overuse is detected, it may dim the lights or issue a voice reminder to take a break.
* When the user leaves home and no presence is detected, the system may **lock the smart door**, **turn off lights**, and reduce heating/cooling to save energy.

These actions are not just suggestions; they are **autonomously triggered**, based on previously learned behavior patterns and optimized using reinforcement learning:



where sss is the current state, aaa is the selected action, rrr is the reward received, γ(gamma) is the discount factor, and α(alpha) is the learning rate.

A **feedback mechanism** ensures adaptability: user responses (acceptance/rejection) and environmental outcomes continuously improve the model’s decisions.

where sss is the current state, aaa is the selected action, rrr is the reward received, γ(gamma) is the discount factor, and α(alpha) is the learning rate.

Feedback is incorporated both implicitly (through sensors measuring outcomes) and explicitly (through user interaction (acceptance/rejection) or acceptance of recommendations), allowing the system to improve over time.

In essence, the system transforms passive smart devices into **proactive, behavior-aware agents**. By recognizing patterns and automating repetitive tasks, it reduces cognitive load on the user while encouraging healthier routines and greater efficiency.

The CNN acts as a feature extractor that transforms raw, high-dimensional sensor input into meaningful states for the agent. Q-learning then learns a state-action policy π(s) that maximizes expected long-term reward

### **4.5 Procesul de proiectare și dezvoltare a arhitecturii**

Arhitectura soluției propuse a fost construită iterativ, pornind de la cerințele identificate în etapa de analiză (Capitolul 2) și scenariile reale de utilizare. Alegerea unei structuri pe 3 nivele a permis separarea clară între colectarea datelor, interpretare și decizie, asigurând modularitate și scalabilitate.

Decizia de a folosi modele de tip CNN și CNN-LSTM a fost fundamentată pe caracterul spațial și temporal al datelor colectate, iar utilizarea DDQN a fost motivată de necesitatea unui agent care poate învăța acțiuni optime în contexte variabile și incerte. Alegerea acestor algoritmi s-a bazat atât pe revizuirea literaturii de specialitate (vezi Capitolul 3), cât și pe experimentări preliminare efectuate în Python cu seturi de date similare.

Integrarea senzorilor și a componentelor hardware s-a făcut pe baza unei selecții din dispozitive compatibile cu platforma VikiKnows, adaptate la cerințele comportamentale definite în modelul logic dezvoltat în secțiunea X.

## Indicații formatare formule

Formulele matematice utilizate în document vor fi centrate în pagină și numerotate. Se vor utiliza fontul Cambria Math, de dimensiune 11. Pentru a insera o nouă ecuație, utilizați Insert > Quick Parts > AutoText > Ecuație.

Toate formulele prezente în lucrare vor fi referite în text. Exemplu: *Utilizând sistemul de Insert > Bookmark*, respectiv *Reference > Cross-reference* putem cita ecuația (1) respectiv ecuația (2), citările fiind actualizate și în urma unor adăugări/ ștergeri de ecuații, cu *Select All – Update Field*. Pentru mai multe detalii despre utilizarea acestui sistem de referire și formatare puteți consulta:

<https://www.youtube.com/watch?v=9YGTH4WrY_8>.

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

# Detalii de implementare

În plus fata de capitolul precedent acesta conține elemente specifice ale rezolvării problemei care au presupus dificultăți deosebite din punct de vedere tehnic. Pot fi incluse configurații, secvențe de cod, pseudo-cod, implementări ale unor algoritmi, analize ale unor date, scripturi de testare. De asemenea, poate fi detaliat modul în care au fost utilizate tehnologiile introduse in capitolul 3.

Criterii pentru calificativul Nesatisfăcător:

* Sunt prezentate pe scurt scheme și pseudo-cod.

Criterii pentru calificativul Satisfăcător:

* Descriere sumara a implementării, prezentarea unor secvențe nerelevante de cod, scheme, etc.

Criterii pentru calificativul Bine:

* Descrierea detaliată a algoritmilor/structurilor utilizați; Prezentarea etapizată a dezvoltării, inclusiv cu dificultăți de implementare întâmpinate, soluții descoperite; (dacă este cazul) demonstrarea corectitudinii algoritmilor utilizați.

The implementation of the system integrates multiple algorithmic components across supervised learning, unsupervised learning, and reinforcement learning, in order to support complex, adaptive behavioral analysis and automation.

For **state and activity recognition**, we implemented a **CNN-LSTM architecture**, which combines spatial feature extraction from raw sensor inputs (e.g., motion, temperature, sleep data) using convolutional layers, with temporal modeling using LSTM units. This enables accurate classification of activities such as sleeping, eating, physical movement, or prolonged inactivity.

To detect previously unseen patterns in user behavior, we applied **unsupervised learning algorithms** such as **K-means** and **DBSCAN**, enabling clustering of behavioral data without predefined labels. We also utilized **Hidden Markov Models (HMM)** to model sequential activity patterns across time, especially useful in understanding habitual routines and transitions.

The **decision-making core** of the system is based on **Double Deep Q-Learning (DDQN)**, a reinforcement learning algorithm that improves over the classic DQN by reducing overestimation bias through separate target and evaluation networks. The agent receives environmental states (e.g., user\_is\_sleeping, room\_temp=18°C, energy\_usage=high) and selects actions (e.g., increase\_temp, send\_notification, turn\_off\_light) to optimize long-term rewards. The **reward function** is a composite metric based on user feedback (acceptance or rejection of recommendations), improvements in key health indicators (e.g., sleep quality, activity level), and energy/resource efficiency.

As a secondary classifier, we employed a **Random Forest model**, selected for its robustness and interpretability across heterogeneous sensor inputs. This model was used to enhance early-stage behavior recognition and assist the reinforcement learning agent in understanding context.(??? redundant zic eu)

A key technical challenge encountered during implementation was the **synchronization of asynchronous data streams** from wearable devices and smart home sensors. We addressed this using a custom-built **temporal alignment and unification engine**, which normalized timestamps, interpolated missing values, and ensured a clean, queryable time-series dataset stored in a local SQL database.

The system follows a **modular architecture** consisting of three primary layers: (1) the ingestion and unification layer for data collection and preprocessing, (2) the processing core for modeling and decision-making, and (3) the user control layer for chat-based interaction and appliance control. This modularity allowed for staged testing and smooth integration across components.

## Indicații formatare tabele

Se recomandă utilizarea tabelelor de forma celui de mai jos. Font: Calibri, 9.

Orice tabel prezent în teză va fi referit în text; exemplu: a se vedea Tabel 1.

Here's a comparison:

|  |  |  |
| --- | --- | --- |
| Feature/System | Commercial Solutions (e.g., Google Nest) | AI-Driven House |
| **Core Functionality** | Primarily focuses on temperature, lighting, and appliance scheduling based on IFTTT rules or static schedules. Lacks deeper behavioral understanding. | Unifies and manages data from smart home sensors and wearables (smartwatches, rings, fitness trackers) to simplify and enhance user life, with a strong focus on understanding and managing human behavior. |
| **Data Management** | Disparate data sources, often managed independently by different device ecosystems. | Centralized management of diverse personal data (health, habits, energy consumption, food preferences) in one AI system. Data is stored in an SQL Database. |
| **Personalization** | Limited adaptability; models may be generalized, leading to unintended user behavior changes. | Provides personalized commands and feedback, adapting to user habits and preferences by gaining control over home appliances (fridge, AC, HVAC, robot vacuum, door unlocking). A custom-made LLM offers suggestions based on newly found data.  Users can interact via a chat interface to set preferences. |
| **Deployment & Security** | Often cloud-dependent, raising privacy concerns. | Runs entirely locally on a home server, significantly diminishing the risk of cyber attacks and enhancing privacy. This addresses critical concerns about data privacy and security in AAL systems. |
| **Scope** | Primarily focused on environmental control (e.g., thermal comfort). | Integrates health and productivity feedback, extending beyond mere temperature control to optimize aspects like sleep quality, energy consumption, and daily tasks. The project aims to reduce time spent on mundane tasks. |

### **Reinforcement Learning Methods Side-by-Side**

Academic research has seen various RL methods applied to smart homes.

|  |  |  |  |
| --- | --- | --- | --- |
| RL Method / Approach | Application in Smart Homes | Strengths | Limitations/Considerations |
| **Q-Learning** | Used in the Suman et al. (IEEE TAI 2022) study for a smart home model to adapt to human thermal preferences based on activities. Also used to control indoor ventilation to maintain air quality by learning CO2 generation rates. | Enables the smart home to learn optimal policies for maximizing human comfort by adjusting parameters like temperature and humidity based on feedback. | Can lead to unintended behavior changes in users if models are improperly generalized or if the smart home exploits assumptions in the environment. |
| **Hierarchical Reinforcement Learning (HRL)** | Employed in the Suman et al. study for the human model to learn activity switching and setting temperature/humidity for thermal comfort. | Efficiently models the human agent's ability to switch between activities. | Similar to Q-learning, can lead to unexpected behavioral changes in human models. Unintended behaviors are present with models that have less overlapping comfort ranges and different reward structures in multi-human scenarios. |
| **Double DQN (DDQN)** | Used for controlling ventilation and maintaining air quality while minimizing energy consumption. The project specifically chose DDQN over vanilla Q-learning. | Improved convergence and stability compared to vanilla Q-learning. Chosen for its enhanced performance in the proposed system. |  |
| **Deep Neural Networks (DNNs)** | Used to predict energy consumption patterns and for activity recognition and fall detection in Ambient Assisted Living (AAL) systems. | Effective in processing large volumes of data and learning complex patterns for predictive analytics. | Still face limitations in adapting to multiple users, generalizing across environments, and incorporating continuous feedback. |
| **CNN-LSTM Networks** | Preferred in the project over simple RNNs. | Ability to capture spatial-temporal dependencies in sensor data, offering better performance for time-series data analysis. |  |
| **Hidden Markov Models (HMM)** | Applied for action recognition using colorized depth maps. | Useful for modeling time-series sensor data and detecting patterns in user activity. | Interpretability and reactivity vary depending on the scenario. |
| **Random Forests** | Used for signal classification for movement tracking using wearable sensor data. | Effective for classifying signals from wearable and mobile sensors. | Interpretability and reactivity vary depending on the scenario. |
| **Unsupervised Learning & Pattern Analysis** | Employed in the" project. | Identifies and modifies user behavior through adaptive interventions. Useful for discovering unknown patterns in behavior or health conditions. |  |

### 

Tabel 1 – Sumarizare criterii

|  |  |  |
| --- | --- | --- |
| Calificativ | Criteriu | Observații |
| Nesatisfăcător | Sunt prezentate pe scurt scheme și pseudo-cod |  |
| Satisfăcător | Descriere sumara a implementării, prezentarea unor secvențe nerelevante de cod, scheme, etc. |  |
| Bine | Descrierea detaliată a algoritmilor/structurilor utilizați; Prezentarea etapizată a dezvoltării, inclusiv cu dificultăți de implementare întâmpinate, soluții descoperite; (dacă este cazul) demonstrarea corectitudinii algoritmilor utilizați. | Pot fi incluse configurații, secvente de cod, pseudo-cod, implementări ale unor algoritmi, analize ale unor date, scripturi de testare. |

# Bibliografie

* Trebuie respectat **un singur standard** de trimiteri bibliografice (citare), **dintre** următoarele alternative:
  + APA (<http://pitt.libguides.com/c.php?g=12108&p=64730>)
  + IEEE (<https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf>)
  + Harvard (<https://libweb.anglia.ac.uk/referencing/harvard.htm>)
  + Cu numerotarea referințelor în ordine alfabetică sau în ordinea apariției în text (de exemplu, stilul cu numere folosit de unele publicații ACM - <https://www.acm.org/publications/authors/reference-formatting>)
* Toate referințele din acest capitol trebuie să fie referite în text. Exemple:
  + [Articol jurnal]: [2];
  + [Articol conferință]: [3];
  + [Weblink]: [5]
  + [Application report] [6]

|  |  |
| --- | --- |
| [1] | J. Silva-Martinez, "ELEN-325. Introduction to Electronic Circuits: A Design Approach," 2008. [Online]. Available: <http://www.ece.tamu.edu/~spalermo/ecen325/Section%20III.pdf>. |
| [2] | H. Baali, H. Djelouat, A. Amira and F. Bensaali, "Empowering Technology Enabled Care Using IoT and Smart Devices: A Review," *IEEE Sensors Journal,* vol. 18, no. 5, pp. 1790-1809, 2018. |
| [3] | A. Haroon, S. Akram, M. A. Shah and A. Wahid, "E-Lithe: A Lightweight Secure DTLS for IoT," in *IEEE 86th Vehicular Technology Conference (VTC-Fall)*, Toronto, 2017. |
| [4] | A. K. Jain and R. C. Dubes., Algorithms for Clustering Data, Upper Saddle River: Prentice-Hall, Inc., 1988. |
| [5] | "Kernel panic! What are Meltdown and Spectre, the bugs affecting nearly every computer and device?," techcrunch.com, 2018. [Online]. Available: https://techcrunch.com/2018/01/03/kernel-panic-what-are-meltdown-and-spectre-the-bugs-affecting-nearly-every-computer-and-device. [Accessed 14 02 2018]. |
| [6] | E. Rogers, "Understanding Buck-Boost Power Stages in Switch Mode Power Supplies," Texas Instruments, 2007. |

* NU utilizați referințe la Wikipedia sau alte surse fără autor asumat.
* Pentru referințe la articole relevante accesibile în web (descrise prin URL) se va nota la bibliografie și data accesării.
* Mai multe detalii despre citarea referințelor din internet se pot regăsi la:
  + <http://www.writinghelp-central.com/apa-citation-internet.html>
  + <http://www.webliminal.com/search/search-web13.html>
* Note de subsol se utilizează dacă referiți un link mai puțin semnificativ o singură dată; Dacă nota este citată de mai multe ori, atunci utilizați o referință bibliografică.
* Dacă o imagine este introdusă în text și nu este realizată de către autorul lucrării, trebuie citată sursa ei (ca notă de subsol sau referință - este de preferat utilizarea unei note de subsol).
* Referințele se pun direct legate de text (de exemplu „KVM [1] uses“, „as stated by Popescu and Ionescu [12]”, etc.). Nu este recomandat să folosiți formulări de tipul „[1] uses”, „as stated in [12]“, „as described in [11]“ etc.
* Afirmațiile de forma „are numerous“, „have grown exponentially“, „are among the most used“, „are an important topic“ trebuie să fie acoperite cu citări, date concrete si analize comparative.
  + Mai ales în capitolele de introducere, „state of the art“, „related work“ sau „background“ trebuie să vă argumentați afirmațiile prin citări. Fiți autocritici și gândiți-vă dacă afirmațiile au nevoie de citări, chiar și cele pe care le considerați evidente.
  + Cea mai mare parte dintre citări vor fi în capitolele de introducere „state of the art“, „related work“ sau „background“.
* Toate intrările bibliografice trebuie citate în text. Nu le adăugați pur și simplu la final.
* Nu copiați sau traduceți niciodată din surse de informație de orice tip (online, offline, cărți, etc.). Dacă totuși doriți să oferiți, prin excepție, un citat celebru - de maxim 1 frază- utilizați ghilimele și evident menționați sursa.
* Dacă reformulați idei sau creați un paragraf rezumat al unor idei folosind cuvintele voastre, precizați cu citare (referință bibliografică) sau cu notă de subsol sursa sau sursele de unde ați preluat ideile.

# Anexe

Anexele sunt opționale.

Ce poate intra în anexe:

* Exemplu de fișier de configurare sau compilare;
* Un tabel mai mare de ½ pagină;
* O figura mai mare mai mare de ½ pagină;
* O secvență de cod sursa mai mare de ½ pagină;
* Un set de capturi de ecran („screenshot”-uri);
* Un exemplu de rulare a unor comenzi plus rezultatul („output”-ul) acestora;
* În anexe intră lucruri care ocupă mai mult de o pagină ce ar întrerupe firul natural de parcurgere al textului.