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LOCATION-BASED SERVICES IN UBIQUITOUS COMMUNICATION SYSTEMS

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While attending a lecture of Computer Networks, during my masters in Management Information Systems, I met the professor Manos Roumeliotis. He introduced us to professor Konstantinos Psannis. The latter was the one that urged me to make some research on **big data** and **signal filtering**. It seemed quite interesting and I wanted to make research in order to contribute in this topic. Professor Roumeliotis agreed and it was then, that I started my research. I want to thank all my professors and tutors for all help provided to me, as well as my friends and family for the support. Moreover, special thanks to professor Roumeliotis and Psannis for their support and help during my research and to professors Ksinogalos and Protogeros for their patience and time during their lectures about programming.

ABSTRACT

There are many approaches and models regarding the localization of a mobile terminal. However, each one of them has both advantages and disadvantages. Nowadays, the challenging issue is not only localization, but tracking as well. In this project, related work will be studied, concerning approaches of modifications and optimizations of current models as well as novel proposals, in order to provide a quality review of them, according to challenging criteria, such as accuracy, latency and efficiency. Furthermore, there is a theoretical proposal of a modification or even a potential merging of the studied related work. Specifically, a theoretical Hidden Markov Model-based model is proposed, modified with a novel map-aware model, to improve accuracy and latency. The development of the proposed scheme is considered to be future work, however, an experimental analysis is conducted to test the viability and efficiency of the map-aware modification.

KEYWORDS: LOCATION-BASED SERVICES, COMMUNICATION SYSTEMS, LOCALIZATION, TRACKING, EVALUATION, SIGNAL FILTERING, HIDDEN MARKOV MODEL, HMM

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1. Introduction

1.1. History of location-based services

A **location-based services** (**LBS**) are software-level services that "gather and deliver" location data [1, p. 1] to control features. By the "**location**" term we refer to the geographical term that is used to identify a place in the real world [1, p. 17]. Place can be interpreted as a spot or an area over the surface of earth. However, location term can be scaled to many subcategories regarding to the application of the services. As such LBS is an information service and has a number of uses in social networking today as information, in entertainment or security, which is accessible with mobile devices through the mobile network and which uses information on the geographical position of the mobile device [2, p. 176]. LBS can be used in a variety of contexts, such as health, object search, entertainment, work, personal life, tracking, etc. So the LBS term can include many services [3]. For example, services from person positioning and tracking to bank account transactions tracking, parcel/vehicle tracking services and mobile commerce (coupons or location-based advertising), as well as, personalized weather services and even location-based games [4]. LBS has become critical to many businesses and governments as well. Real insight can be provided by processing data related to a specific location where specific activities take place. Those location-related data and services can provide spatial patterns that can be leveraged to better understand patterns and relationships in those activities. [4] [1, pp. 1-7,35-49] Eventually, "Location-based Services" can be considered "a vehicle for telecommunication convergence". [5, p. 2] [6, p. 12]

Nowadays, LBS are "part of virtually all control and policy systems" [7] which works in our computers and smart devices. They have evolved from simple synchronization based service models to authenticated and complex tools for implementing virtually any location based service model or facility [8, p. 59]. They are the ability to open and close specific data objects, based on the use of location and/or time as controls and triggers or even as part of a cryptographic key or hashing systems, and the data those objects provide access to. [6, p. 12] LBS are part of everything, from control systems to smart

weapons. They consist the most heavily used application-layer decision framework in computing today. [9, pp. 919-921]

1.2. Significance of location-based Services

The knowledge of the location of mobile node can give us some information, however, the knowledge of the location of the node over a time period can give us its moving trace. So another piece of information that LBS help us to obtain is **tracking** information. By tracking we refer to the computation of an object placement relative to a real world element or location over a time period. The challenge is to **predict the tracking path** by studying the node's behaviour. The **behaviour** term contains too much information. Concerning this field of research, we can incorporate in the term information attributes like **location**, **velocity**, **acceleration**, **tracking activity**, **time**, **distance** and many other variables depending on which specific field we are researching (**temperature**, **air/water pressure**, etc) (figured by studying related work). Thus, in order to predict the tracking path, we can focus on accurately predicting the next location(s) of the observed subject. To achieve this, it will be a major help if we can get access to the area geographic and morphological information. Such knowledge can provide us normalization patterns to lessen errors like placing a driving inside the sea near the road since due to signal conflicts.

1.3. Problem definition

There are many approaches to figure out an optimization to location-based services. Some of them, that demonstrate significant results, use algorithms as well as applied combinations of filters such as Particle, Kalman or extended Kalman. Furthermore, another model that is used to solve such problems is the Hidden Markov Model. [10, pp. 354-380] Its use on location-based services can optimise tracking's accuracy and latency, as well as used for machine learning to improve latency issues or even reveal abnormal activities, such as tracking paths that deviate safe area.

In this project, selected related works on localization and tracking have been studied, in order to provide a quality comparison of them, resulting to figuring a probable optimization of them or even a potential merging, to optimize Location-based

services. To begin with, however, we need to understand the problem that needs optimization.

Firstly, **localization** of an object can be as explained as the process of positioning it regarding the surface of the earth. Also, knowing the next locations results in **tracking** the object's route. This is how localization and tracking are connected.

In continue, **tracking** is an issue that needs optimization. However, what do we mean with tracking? Tracking is the ability to know the precise **location** of something over time. In the term location, there are many attributes that can be included for security or privacy reasons. The major challenge is to collect and use **data** that can help use **predict** the **following location** of the mobile device or user. **Velocity** is a major attribute that can help us predict if the user is going to **stop**, **turn**, or even **crash** somewhere. This attribute should be studied in relevance to **time**, so that we know about the acceleration of the device. Additionally, localization is relevant to the terrain, thus terrain data should be utilized somehow to achieve mush more efficient results.

To sum up, a **modification** is essential to cover up the **velocity and acceleration parameters** as well as to include **terrain data** in our computations, which cannot be solved my HMM as is. Last but not least we need **many data points** to have "**continuous**" **information** and **avoid conflicts** and **diminish** the **NLOS error** as well. Input and output data should be somehow parted to solve the **big data** issue and scale the model to cover huge networks as well as areas. Finally, an algorithm such as the **Hidden Markov Model** (HMM) will be needed to optimize the machine learning part with its **pattern recognition** applications.

1.4. Research Objective

In this project, a research will be conducted regarding related work of modifications, optimizations as well as novel approaches and models that have been proposed to cure this localization and tracking issue. The main contribution of this research will be a quality evaluation of those approaches and proposals, visualized in a table of evaluation. Moreover, a theoretical approach to a novel and robust model, concerning a merging and modification of related work studied, will be presented, in order to be developed as future work.

1.5. Project Outline

In section 1, there is the Introduction where a brief historical reference to LBS and their significance is made, followed by the problem definition and the objective of this project-research. In the next section related works that are used to conduct this researched are reviewed, in order to figure the main idea of each proposed approach. Section 3 is about the methodology that was used to complete the whole project. There is an analysis of the selection of the resources used, as well as the method used to evaluate them and complete the table of evaluation. In continue, there is a chapter concerning the experimental analysis of a quite simplified version of the map-aware model part of the projects proposal to test its viability for future development. In section 4, the criteria used to evaluate the related work are explained and the Table of Evaluation is being analyzed. Proposed modifications and the novel approach is explained in section 5, where there is a theoretical approach to the models architecture and a flow chart to visualize it. Moreover, the comparative objective of this novel approach is explained. An estimate scalability of the approach is presented, followed by the experimental analysis chapter, where the results are demonstrated and explained. In section 6 there is a chapter about future work and the conclusion. In the end of the project, there is the Appendix A section where the Java code that was used in experimental analysis is available.

2. Related Work

1.6. Introduction

In this section, there is some related work of approaches and proposals that I studied and reached to an outcome, regarding them, contributing in my approach. Apart from them, I used some other sources to study signal filtering and acquire information concerning the history and applications of LBS. In the following chapter there is a brief sum of the main idea from each paper.

1.7. Related Work

1) An Indoor Mobile Location Estimator in Mixed Line of Sight/Non-Line of Sight Environments Using Replacement Modified Hidden Markov Models and an Interacting Multiple Model

As seen in [[11]], the hidden Markov model (HMM) filter is a grid-based method that uses Bayesian techniques to estimate the location, because there is a location variable in the algorithm. Since we are dealing with both LOS and NLOS situations the MT has a dynamic state matrix, in which there is the transition probability. It is analyzed into Position Transition probability and sight Transition probability.

Modified Hidden Markov Model (HMM)

A problem with HMM after the location of the MT is fixed, there is no further modification because efficiency will be reduced. The modifications made stand for improving the localization precision, by placing weights on both Transition and Observation probabilities.

Replacement Modified Hidden Markov Model (RM-HMM)

This is an enhanced version of the previous modification, in which the probabilities for each state per calculation moment are according to the most accurate ones, which can be explained as the replacement of a latest transition probability with the previous one respectively.

Hidden Markov Model (HMM) + Interacting Multiple Model (IMM)

However, the previous is deficient because, in practice, the transition probability matrix should not be unique for variable motion of the MT. This approach to solve the problem is to create several separate transition probability models and derive results depending on the velocity distribution in each. The Interaction Multiple Model (IMM) estimator approach is a dynamic system with multiple switching probabilities used to select the proper transition probability model at the appropriate time, making use of the velocity. There are separate velocity distributions corresponding to a reasonable probability function. The Markov switching model is choosing the right model. The Cramér–Rao Lower Bound is used for the Localization Error in NLOS Environments.

2) Cooperative Positioning and Tracking in Disruption Tolerant Networks

Acoording to [12], Localization in Disruption Tolerant Networks faces two major difficulties: the mobile node can only use sparse reference points to estimate its location, and the tracking server need to determine and predict movement trajectories with partial location information. To overcome these difficulties, PulseCounting and ProbTracking where proposed for positioning and tracking in Disruption Tolerant Networks. The proposed model is Markov-based. It is designed for a region with devices, Access Points (Aps) and an Infostation, which is a server connecting to the APs.

PulseCounting

This is a method for decentralized cooperative positioning in Disruption Tolerant Networks (DTNs). It consists six steps:

→ Bootstrapping

→ Step Counting

→ Direction Mapping

→ Trajectory Generation

→ Location Estimation

→ Refinement, which is divided into

- *Reference Point-based* and

- *Mutual Refinement*

This method to work needs the Infostation to be updated by the device.

ProbTracking

This is a probabilistic tracking method aiming to create the device's trajectory from incomplete measurements, since the device is not real-time updating the Infostation.

Combination of cooperative self-localization (CS) and distributed object tracking (DT)

This approach is about a consistent combination of cooperative CS and DT for multiple mobile or static agents and objects as well. The results from ProbTracking are corrected and updated as long as the device communicates with the Infostation.

3) Distributed Localization and Tracking of Mobile Networks Including Non-cooperative Objects

To evaluate [13] we need to understand its contribution. This approach is for distributed localization and tracking of cooperative agents and non-cooperative objects in wireless networks, using measurements between agents and objects and between agents. This method, for the first time, provides a consistent combination of CS and DT in decentralized agent networks where the agents and objects may be mobile. To the best of our knowledge, it is the first method for simultaneous CS and DT in a dynamic setting. For a distributed operation and low complexity, we combine particle-based belief propagation with a consensus or gossip scheme.

4) Refining Wi-Fi Based Indoor Localization with Li-Fi Assisted Model Calibration in Smart Buildings

In continue, this approach (in [14]) takes advantage of smart buildings. Since Wi-Fi services are tending to be upgraded to Li-Fi, a more efficient Li-Fi localization method is proposed, that as well should be integrated to smart buildings' resident-services. This approach is focusing on improving the QoS of the visitors as well. Tracking of them inside the facilities will help informing the smart building how to adjust the services, temperature, lights, etc. Despite being an indoor approach, it can cover huge buildings and Wi-Fi is quite scalable to going outdoors, communicating with other buildings as well.

5) Mobile Location with NLOS Identification and Mitigation Based on Modified Kalman Filtering
(NLOS id + Mitigation based on MKF)

In [15], a modified Kalman Filtering is proposed. To improve location accuracy, an NLOS identification and mitigation algorithm has been integrated to the Kalman

filtering algorithm. The performance gain has increased computer time, however, it can be recommended for real-time applications.

6) Particle Filters (PFs) for State Estimation of Jump Markov Linear Systems

According to paper [16], there are proposed online simulation-based algorithms to perform optimal filtering and fixed-lag smoothing of Jump Markov Linear Systems (JMLS). Those proposals are quite complex, however, they can be straightforwardly implemented on real-time applications, if we use parallel computer systems.

7) Position and Velocity Tracking in Mobile Networks Using Particle and Kalman Filtering with Comparison

As analysed in [17]:

MLE APPROACH FOR MS LOCATION ESTIMATION

A Maximum Likelihood Estimation (MLE) approach is presented to estimate the initial location of the Mobile Station (MS). The MLE approach employs a lognormal propagation channel model. The estimated location is used as the initial state of the EKF approach for the MS final location estimation. Thus, we have a hybrid EKF approach.

EKF APPROACH FOR MS LOCATION AND VELOCITY ESTIMATION

Moreover, a Particle filter (PF) approach for MS location and velocity estimation is proposed. The Unscented Particle filter (UPF) is implemented, however, it approximates the optional distribution by a Gaussian distribution using the Scaled Unscented Transformation (SUT) method. This SUT method accurately calculates the posterior covariance to the third order, whereas linearization methods such as the EKF rely on a first-order biased approximation.

8) A 2.4 GHz ISM RF and UWB hybrid RFID real time locating system for industrial enterprise Internet of Things

As seen in [18], the Internet of Things (IoT) platform consists of a two-layer network hierarchy that employs heterogeneous networks is connected to the Internet through a standard air interface, such as Wi-Fi, GSM/GPRS and 3G. The sensing layer, which is the RFID system where sensor nodes (RFID tags) are coordinated by base stations (readers) through an ultra-low-power short-range wireless link. In the second layer, ad-hoc networks among RFID readers, working as the wireless sensor network, are utilized to perform data interaction.

The proposed system is a hybrid one and it consists of a server with a locating engine, the reader networks and the 2.4-GHz RF and UWB hybrid tags. The 2.4-GHz readers adopting the RSS method are employed to provide metre-level positioning accuracy and the UWB readers are deployed in the critical areas for fine position estimates. The UWB reader is basically a ranging receiver to detect ToA information of UWB pulses from tags. Therefore, the tag's position is calculated by a TDoA algorithm, that is, different ToAs received by more than three different readers for location estimates. The hybrid tag consists of a 2.4-GHz transceiver and a UWB transmitter. this approach avoids a power-hungry UWB receiver and complex communication protocol, thus maximizing the battery life for extended maintenance cycles.

9) Hybrid Unified Kalman Tracking Algorithms for Heterogeneous Wireless Location Systems

In this paper [19], hybrid unified Kalman tracking (HUKT) technique is proposed. It is an integrated algorithm for precise location tracking based on both time of arrival (TOA) and time difference of arrival (TDOA) measurements. The major design novelty of the HUKT scheme is that the nonlinear parameters within their respective TOA and TDOA-based location estimators are mathematically combined into a single state variable, which is to be updated within the Kalman filter. A new variable is incorporated as an additional state within the Kalman filtering formulation to consider the nonlinear behavior in the measurement update process. The

relationship between this new variable and the desired location estimate is applied in the state update process of the Kalman filter. For adjusting the weighting value between the TOA and TDOA measurements, three different designs of hybrid factor are proposed. The Hybrid factor is a Geometric Dilution of Precision (GDOP) based factor (GHF). The GDOP describes the geometry influence on location estimation accuracy. Therefore, the GDOP criterion that provides the relative distance information between the MS and BSs can be utilized to determine the hybrid factor that represents the weighting between the TOA and TDOA measurements. Furthermore, the proposed HUKT algorithm can directly be simplified into a unified KT (UKT) scheme for location tracking under the situation with only homogeneous signal sources. An UKT-TOA based scheme and a UKT-DTOA-based one are proposed.

10) Adaptive tracking of people and vehicles using mobile platforms (DTSMD)

In this paper [20], the design of a data-driven tracking system that integrates computational and measurement processes for optimized operation and reliability on mobile devices, is presented. That design is developed by integrating state-of-the-art acoustic-sensor-based tracking algorithms with principles of dynamic, data-driven application systems (DDDAS) and dataflow-based design and implementation of signal processing systems. The proposed tracking system design is called DDDAS-enabled Tracking System for Mobile Devices (DTSMD). DTSMD incorporates measurements throughout application operation to help the system adaptively select tracking algorithm configurations that are most strategic in terms of trade-offs among accuracy, energy efficiency, and real-time performance.

11) High-accuracy vehicle localization for autonomous warehousing

In this paper [21], there are combined several well established algorithms into a high-precision localization pipeline, capable of computing the pose of an autonomous forklift to sub-centimeter precision. The algorithms use only odometry information from wheel encoders and range readings from an on board laser scanner. The effectiveness of the proposed solution is evaluated by an extensive

experiment that lasted for several days, and was performed in a realistic industrial-like environment. During three days and 19 hours of total travel time, the vehicle has logged over eight kilometers, relying only on map information and its sensor readings, without a single failure or operator intervention. The localization experiments have been performed at the Euroimpianti manufacturing and testing facility in Schio (VI), Italy. It consists of an 80 m by 50 m main hall and a 20 m by 50 m storage area. The main hall is used for assembling and testing palletization lines and AGVs, with over 30 people working there on a typical day.

An overview of the localization algorithm proposed:

Adaptive Monte Carlo Localization (AMCL) Algorithm is used to fuse odometry data with laser range measurements to provide a robot's pose estimate with a known covariance. In continue, this result is used as an estimate for the scan matching Iterative Closest Point (ICP) algorithm. Finally, he obtained result is used as the initial estimate in a discrete Fourier Transformation method, which returns the final result.

12) Message of Interest: A Framework of Location-Aware Messaging for an Indoor Environment

The goal of this paper [22] is to develop and deploy a location-aware messaging framework that is based on indoor location detection. This framework will only deliver messages when users are at work. The system uses beacon technologies to accurately deter-mine the position of a user inside a building. The users, in return, communicate with the system using an application running on their smartphones. The framework delivers customized messages according to the user. This proposal is applicable on smart buildings, however. This approach concerns indoor as well as outdoor users. This framework, also, consists of OWNERS and VISITORS. An OWNER will adjust the message delivery settings and compose it. Each user has a specific signature. If the user is the BEACON-LISTENER, he will receive the message/notification when he will reach the appropriate range from the BEACON. However, if the message is not forwarded to him he will just be a VISITOR to the beacon and not notified for that. All users will be notified through some smartphone application on their mobile device.

13) An Indoor Continuous Positioning Algorithm on the Move by Fusing Sensors and Wi-Fi on Smartphones

In this paper [23], the proposal is referring to an indoor continuous positioning algorithm that is on the move, fusing sensors and Wi-Fi on smartphones. The main innovative points include:

→ an improved Wi-Fi positioning algorithm:

The algorithm has two phases, the OFFLINE training phase and the ONLINE positioning phase. However, to describe the properties of Wi-Fi signal on the move, there were introduced (proposed) two new parameters, "refresh rate" and "loss rate". The aim of this proposal concerning those two parameters is that they can be deduced in a similar way.

→ the "Trust Chain Positioning Fusion" algorithm (TCPF) which is a positioning fusion algorithm. The TCPF algorithm is proposed to realize **the "process-level" fusion of Wi-Fi** and Pedestrians Dead Reckoning (**PDR**) positioning, including three parts: **trusted point determination**, **trust state** and **positioning fusion algorithm**. The PDR positioning module monitors the walking action of the user, then estimates their step length and orientation to estimate the displacement so that positioning estimation can be realized. An experiment is carried out for verification in a typical indoor environment, and the average positioning error on the move is 1.36 m, a decrease of 28.8% compared to an existing algorithm. The results show that the proposed algorithm can effectively reduce the influence caused by the unstable Wi-Fi signals, and improve the accuracy and stability of indoor continuous positioning on the move.

14) Vehicle Monitoring and Tracking System using GPS and GSM Technologies

In this paper [24], the proposal is about vehicle security. The proposed method is about alerting the vehicle's owner. However, the alerts are not only concerning the position of the vehicle. Alerts about engine status, such as temperature, and speed limit when reaching areas such as schools, playgrounds, hospitals, etc are received as well. GSM circuit's operation is to find the vehicle whenever it is kept in security mode and it communicates directly with the user's smartphone via his

number, which is registered to the service, if the vehicle's position has changed. Then a message can follow which will TURN OFF the vehicle's engine immediately. The approach seems NOT TESTED for the ACCURACY, however, seems quite a security measure.

15) Real-Time Sensor Data Integration in Vertical Transport Systems (AdInspect)

In this paper [25], the proposed method (AdInspect) aims to the monitoring of the QoS and the maintenance of Vertical Transport Systems, like an elevator or a lift car. The proposed solution is an Inertial Navigation System (INS), that will track the system's movement profile. Information, such as velocity and vibration, will be obtained by sensors. However, INS is experiencing ISSUES when velocities aren't low. It has been tested on a **lift car system**. It seems like other channels are needed to obtain accurate information for the acceleration and the gravity vectors, such as GPS information.

16) Emergency Service using GPS Tracking

In this paper [26], a proposal is presented regarding ambulance support to people in distress. The system's architecture consists of two sides: user's side (a smartphone owned by the user) and ambulance's side (dedicated device/android smartphone, owned by the driver or fixed in the ambulance. The user will send an ambulance request and a server will process by forwarding it to the nearest vacant ambulance. When an ambulance accepts the request, a response will be sent to the user from the server and the ambulance will be on its way.

3. Methodology

1.8. Introduction

In this section, the steps followed to complete this project are presented. There is an analysis of the criteria that the selection of the resources was conducted. In the next chapter, the method and the steps I followed to evaluate them and a proposal of a probable merging and optimization are presented.

1.9. Resource selection

There are many approaches to optimize Localization and Tracking. A search was made for resources with relevant keywords such as location-based services, signal filtering, ubiquitous communication systems, Kalman filter, hidden Markov model filter, Particle filter, localization and tracking systems, LTE, fusing sensors and mobile tracking. The resources were filtered according to the technological level of the methods and approaches that they used and to the date of publication. The related work that has been selected are mostly up-to-date, due to the rapid advance of technology. Moreover, there are relevant books like [10] and [1] that I studied to complete the research, as well as resources like [5] and [8] that were used for information concerning the Introduction Section.

1.10. Evaluation and Proposal

After doing some research ways to cure localization and tracking issue I ended up with certain challenging criteria. According to them I evaluated the papers in a Low, Medium, High scale relatively to their contribution on optimising each one of the criteria. The evaluation of the related work is document-driven and based mostly on their results over the simulations and experimental analysis that conducted by their authors. However, there are certain criteria about sectors and problems that where not taken into account on some works, hence evaluation was completed by a personal

estimate according to the authors' referred data. This research's outcome and be seen and explained in the Table of evaluation Section.

After completing the Evaluation Table, proposal of [11] was considered to be more applicable and scalable to optimizations and modifications than the rest. [11] is an approach that is not based that much on hardware and sensors such those in [22], [23] and [24]. Moreover, the proposed model is working with existing infrastructure that can be found almost everywhere, in contrast to [14], which despite being such a novel and contributing approach Li-Fi and smart buildings are not that widespread yet. Hence, I studied more on the HMM filter and its algorithm and how to optimize it. The reason I chose to propose a HMM-based approach is based on its mechanics, scalability and applications. Also, after some more research on map-aware optimized tracking methods apart from GPS-systems, I reached to a novel and robust optimization, combining the proposed model in [11] with a map-aware filter and a pattern recognition scheme. To prove however that it should be researched I made an experimental analysis to test how the proposed map-aware filter will impact on localization and tracking. This modified merging seems a quite promising one, yet it will be considered as future work to develop and test it. Finally, an estimate scalability analysis is presented.

1.11. Experimental Analysis

1.11.1. Introduction

After completing the model's scheme and flow chart, a testing was necessary to proceed to the presentation of the theoretical approach. In this chapter, it is explained how the experimental analysis was conducted. Java code (available in Appendix A) was implemented and measurements were used to simulate the results in Eclipse. The Java project is explained in the Project Specification (according to [27]) chapter.

1.11.2. Project Specification

In this chapter there is an analysis of the Java Project (as guided in [27]) used to simulate an experimental analysis. There are 5 stages in software development [27]. Analysing the requirements, designing the software, implementing it, testing it and writing a documentation about it.

1.11.2.1. Requirements Specification

To prove the proposed model's viability, it was tested in a simplified version. The proposal of map-aware model will be designed to be implemented on a 2^{nd}-grade HMM with and adaptive Transition Probability Table, however, to proceed in this models' development, an experimental analysis was conducted with a comparative simulation of a basic HMM and a modified one with the map-aware logic. Summing up, a HMM Java code was needed to conduct an experimental analysis and if possible a HMM with the Viterbi optimization. The inputs would be 2 Probability Tables[9x9], a Transition and a Noise one and the experiment's measurements, both actual and ones distorted with noise. As outputs, essential would be to get the deviation results from the actual path and the calculated one, as well as the time spent in computing.

1.11.2.2. Software Design

Due to my lack of expertise in programming (one year of experience in Java), designing the software from scratch was almost impossible for me. Hence, I asked from professor Psannis a HMM filter Java code to understand it, and adjust it in the experiment. The code I received was a basic HMM filtering code with the ability of using the Viterbi optimization. The code however was quite hardcoded and there was a usage of GUI libraries (like JFrame) which were quite hard to handle considering my lack of experience. After studying the code and understanding its logic, I was able to proceed on refactoring it for my experimental case.

1.11.2.3. Implementation

I hardcoded the Tables as seen in section 5.10 and provided the measurements as a .txt file. The noise Probability Table was designed by a random function and the Transition Probability Tables of the basic HMM and the map-aware filtered where hardcoded according to the HMM logic and map-aware filtering respectively. The map-aware filtering principle followed when constructing the Transition Probability Table is that the transition probability to or from a not viable state (obstacle or wall) will is set to be 0.

1.11.2.4. Testing

Testing was conducted as a simulation in Eclipse. The experimental case is concerning the tracking of a subject that is already moving and continue to a right turn. There are walls to prevent the subject from taking any other locations than the measured ones and this experiment is an example of a case that usually provide lots of outliers in our measurements, often due to noise and NLOS error. The Actual measurements were stable and presenting the actual tracking route. The noise measurements used the the results obtained are displayed in the following scheme:

actual measurements	noise measurements	results	initial	HMM	ma_HMM	V_HMM	V_ma-HHM
6	6						
3	3	deviation	2.75	1.5	0.5	1	0.5
4	0	time elapsed	-	1.728	2.654	0.075	0.053
5	8						
6	7						
3	3	deviation	1.75	1.5	0	2	0
4	1	time elapsed	-	2.279	2.615	0.055	0.052
5	2						
6	3						
3	0	deviation	2.75	2.5	1.25	2.5	1.25
4	2	time elapsed	-	1.771	1.917	0.077	0.052
5	8						
6	6						
3	0	deviation	2.25	1.5	0.5	1.5	0.5
4	1	time elapsed	-	2.418	1.887	0.056	0.054
5	8						

Picture 1: Experimental Testing Results

1.11.2.5. Documentation

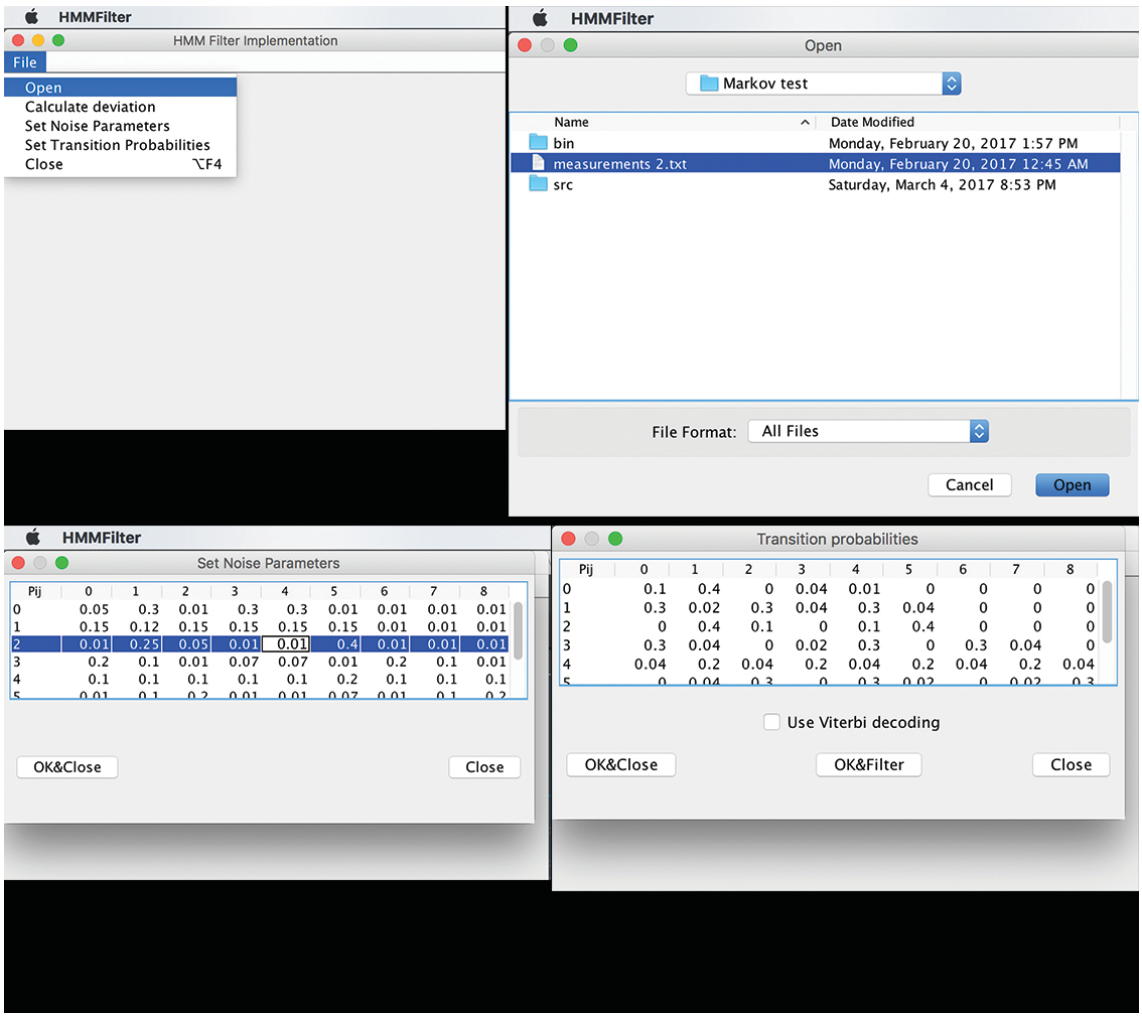
In this Java project objective is to simulate an experimental tracking case to test the map-aware filtering viability. The system is designed with a user GUI (screenshot 1) after running the project from Eclipse. A window is opening and there is a drop down menu.

→The system input is a .txt document with the measurements in 2 columns. In the first column there are the actual measurements and in the second there are the ones distorted with noise. More over there is a Noise Transition Probability table hardcoded in the system.

→ the Noise Transition Probability Table can be altered from the user after running loading the measurements.

→ after setting the Noise Transition Probability Table, the user can alter the already hardcoded Transition Probability Table as well.

→ The user has the option to run the filter and obtain results with or without the Viterbi optimization.

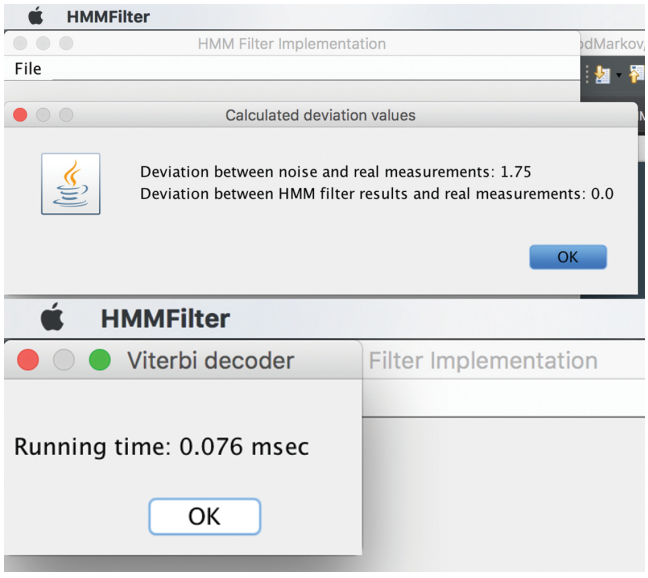


Screenshot 1: GUI of Markov sim in eclipse

The functionality of this project is to provide as outputs (screenshot 2):

→ measurements deviation

→ runtime



Screenshot 2: Markov sim results GUI

The simulation's objective is to reach into a conclusion concerning the viability of the map-aware filtering on the Transition Probability Table in comparison with the existing HMM. The case was tested with multiple measurements in order to achieve more reliable results. The code can be seen in Appendix A.

4. Table of Evaluation

1.12. Introduction

In this section, there is a personal evaluation of the papers mentioned before. The evaluation is based on some criteria that are being analysed in its first chapter, followed by the chapter of the table of evaluation where there is a comparative preview of the papers, referred in the previous section. The last chapter, is about explaining the evaluation table.

1.13. Criteria

The evaluation was based on some criteria of great importance. These are:

→ Communication Channels [CC] (3G, LTE, Wi-Fi) [Net]

→ Accuracy [Acc]

→ Latency [Lat]

→ Real-Time / non Real-Time [RT]

→ Power Consumption [PC]

→ Network Size [NS]

→ Complexity [C]

→ Scalability [Sc]

→ Cost [Cost]

→ Indoor/Outdoor [I/O]

The evaluation scale is **L** (Low), **M** (Medium) and **H** (High):

From **L** to **H** is used to describe weather the proposal is fulfilling the criteria. Thus, the scale can be rephrased as “how much the proposal helps in solving each problem”.

In continue, there is a brief explanation of the criteria used, followed by the evaluation table:

#Communication Channels is referring to weather the system refers to a network with 2G/3G/LTE signals or it incorporates Wi-Fi, Bluetooth, etc communications as well.

#Accuracy refers to the precision of the location’s estimation of each proposal.

#Latency refers to the delay until the desired results. Here the scale goes vice-versa, meaning **H** stands for low latency.

#Real-Time/non Real-Time seems as a **Y/N** scaled criteria. However, according to the evaluation scale of this paper, **L** stands for **non-Real-Time**, **M** for **potentially real-time** and **H** for **Real-Time**.

#Power Consumption is about the energy-saving prospective that the proposal has. The scale goes vice-versa for this criteria as well.

#Network Size concerns the size of the area where the proposal was implemented/tested. Some proposals however have been tested only at simulation-level. They have been evaluated from **L** to **M** according to the simulations' scenario.

#Complexity refers to the algorithms of the proposal. The scale is also vice-versa. The latter is related to the **#Power Consumption** one, cause usually complex algorithms are significantly power hungry, hence they need some serious optimization to become efficient.

#Scalability concerns the proposal's ability to be implemented on different scenarios.

#Cost refers to the funding the will be needed for the implementation of the proposal in real-life.

#I/O stands for weather the proposal is for **Indoor (I)** application or **Outdoor (O)** application. However, the evaluation scale will be **L** for **Indoor**, **M** for **Outdoor** and finally **H** if the proposal can be used for both.

1.14. Table of Evaluation

	CC	Acc	Lat	RT	PC	NS	C	Sc	Cost	I/O
RM-HMM + IMM [11]	**M**	**H**	**H**	**M**	**M**	**L**	**M**	**M**	**M**	**L**
PulseCounting + ProbTracking [12]	**H**	**M**	**L**	**L**	**H**	**M**	**M**	**M**	**M**	**L**
CS + DT [13]	**H**	**M**	**L**	**H**	**M**	**H**	**H**	**H**	**M**	**H**
Li-Fi + Smart Buildings [14]	**M**	**H**	**H**	**H**	**L**	**M**	**H**	**H**	**M**	**L**
NLOS id + Mitigation based-on MKF [15]	**M**	**H**	**M**	**H**	**M**	**L**	**H**	**M**	**M**	**H**
PF for state estimation of JMLSs [16]	**L**	**H**	**M**	**H**	**L**	**L**	**L**	**M**	**M**	**M**
EKF with MLE [17]	**M**	**H**	**H**	**H**	**M**	**L**	**M**	**M**	**H**	**L**
UPF with SUT [17]	**M**	**H**	**H**	**H**	**M**	**L**	**M**	**M**	**H**	**L**
Hybrid RFID (IoT) [18]	**M**	**H**	**M**	**H**	**H**	**L**	**M**	**M**	**H**	**H**
HUKT [19]	**H**	**M**	**M**	**M**	**M**	**M**	**L**	**M**	**M**	**L**
DTSMD [20]	**H**	**H**	**M**	**M**	**H**	**M**	**L**	**M**	**H**	**H**
AMCL+ICP+FT [21]	**M**	**H**	**H**	**M**	**H**	**M**	**L**	**M**	**H**	**H**
Message of Interest [22]	**M**	**H**	**H**	**H**	**L**	**H**	**M**	**H**	**M**	**M**
fusing sensors & Wi-Fi on smartphones [23]	**L**	**M**	**H**	**H**	**M**	**L**	**L**	**M**	**M**	**L**
Vehicle security alerts [24]	**L**	**L**	**H**	**H**	**H**	**M**	**L**	**M**	**M**	**M**
AdInspect [25]	**L**	**M**	**H**	**H**	**M**	**M**	**M**	**M**	**H**	**H**
Emergency Service Using GPS [26]	**M**	**H**	**M**	**H**	**M**	**M**	**L**	**L**	**L**	**H**

Table 1: Table of Evaluation

1.15. Table Analysis

The L/M/H evaluation seems quite “easy”, however, there is more to point than just this table. Some of those proposals didn’t take under consideration all of the criteria, so the evaluation was a bit harsh regarding those factors.

→ To begin with, evaluating [11]:

The main goal of that proposal, as mentioned before, is to eliminate NLOS localization errors in unfamiliar **indoor** environments. Two algorithms to improve the Hidden Markov Model are proposed and a combination of the Hidden Markov Model with an Interacting model as well. Small-scale indoor environments are such, where there are quite many obstacles between the terminal and the access point. The **communication channels** used seems to be just GSM signal, however, it can be quite **scalable** to any indoor signal concerning that the Access Points can receive almost anything. There was small **latency** so it could be considered to be implemented on **real-time** applications. The **accuracy** was quite high so the main goal seems fulfilled. There were no such references concerning **power consumption,** however, the algorithms used are not so power hungry. The testing was conducted with simulation, so the **network size** cannot be evaluated legitimately. The **cost** of the implementation cannot be calculated since it was done on sim, but an estimation can place it on the medium standards. Finally, the **complexity** was quite an issue. In general terms the combination was a quite complex, however the optimizations made on the models where quite simple to understand.

→ In continue, evaluating [12]:

In this paper, the proposal aimed to positioning and tracking in Disruption Tolerant Networks (DTNs). An experiment was conducted on android devices in a Campus, therefore the **network size** can be considered quite adequate. The **communication channels** used where GMS/LTE and GPS. The **power consumption** of this proposal was considered between online radio listening and video watching, so it can be considered quite low, if we are NOT talking about android devices. In this case, since there are some power consumption optimized devices and others extremely power hungry android smartphones as well, energy consumption cannot be considered that low. The proposal is **not real-time** because the mobile terminal must update the “infostation” to work, thus the **latency** is quite high. Regarding **accuracy**, it deviates 9m to the GPS so it’s not quite accurate. Future work can make this proposal more **scalable** and increase the

communication channels used. Finally, he proposal was tested **outdoors** and the **cost** of implementing was not high.

Wi-Fi and Bluetooth can be integrated to the system, in order to have more channels to update the “infostation” and so the proposal can go **real-time**.

→ Evaluation of [13]:

In this paper, the proposal is a Bayesian method for distributed sequential localization of mobile networks composed of cooperative agents as well as non-cooperative objects. In this method there is a combination of cooperative self-localization (CS) and distributed tracking (DT). By combining particle-based belief propagation with a consensus or gossip scheme, low **complexity** is achieved. Moreover, high localization **accuracy** is achieved through a probabilistic information transfer between the CS and DT parts of the underlying factor graph, yet not that high compared to other proposals studied. Simulation results demonstrate the **efficiency** of such a combination, and very good **scaling** properties with respect to the numbers of agents and objects. The proposal can cover many **communication channels** and the **network size** of the sim was more than adequate. The algorithm is not complex and its application seems **not** that **power hungry** as well. No reference is made concerning the **cost** of the implementation, however, it seems of average expense. Finally, even though this is a **real-time** applicable algorithm, for both **indoor** as well as **outdoor** applications, the **latency** issue is quite major and needs to be fixed.

→ Evaluating [14]:

This paper presents a new Wi-Fi based indoor localization technique, that achieves significantly improvement of **indoor** positioning accuracy with the help of Li-Fi assisted coefficient calibration. Therefore, the feasibility of indoor hybrid Wi-Fi and Li-Fi based positioning technique is investigated. The **Communication Channels** used are just Wi-Fi and Li-Fi, however Li-Fi is not that “popular” yet. The **network size** is limited to the inside of the building, however, buildings can be huge. The **accuracy** of the proposed method is quite high and **latency** seems to have been diminished. It is a **real-time** approach and not that **complex**. It can be **scalable**, since Wi-Fi infrastructure and Li-Fi as well can be expanded outside of the involved buildings. Furthermore, since smart buildings are involved, infrastructure must exist in them, thus the **cost** is somehow dropping down. Finally, the **power consumption** of a mobile terminal using Wi-Fi is quite optimized. The back end, however, is yet to be evaluated.

→ Evaluation of [15]:

In this paper, the proposal is quite **NOT complex** and supports **real-time** applications. The **accuracy** is quite high, yet the **latency** numbers need fixing. The **communication channels** that where supported are not all that are used in everyday life, however, it is quite **scalable** to covering them. Low complexity of the proposal renders it **not** that **power hungry.** The **cost** of applying the proposal can be estimated to be between average boundaries, however, there is no such estimation or reference from the authors. Last but not least, the **network size** cannot be evaluated as adequate since the tests were conducted only as simulations and not in a real environment. Finally, the proposal can be implemented on **indoor** as well as **outdoor** applications.

→ Evaluating [[16]]:

This proposal is an approach tested with a simulation. Therefore, the **communication channels** were used in a theoretical level and the **network size** cannot be evaluated. In spite of that, the small **latency** and high **accuracy** measurements, rendered the approach reliable for **real-time** applications. The **complexity** of the algorithms used seems quite high, hence, this approach is rather a **power hungry** one. Future work as well as the approach's description implies **scalability**, however, no reference is made concerning the **cost** of its application. Finally, this approach seems able to be applied for both **outdoor** and **indoor** projects as well.

→ Evaluation of [17]:

In this paper, there is a presentation of two algorithms. The one is an **extended Kalman filter based** modified by using the **maximum likelihood estimate** as an **initial state**, and the other is an **unscented Particle filter based** modified by approximating the optional distribution by a **Gaussian distribution** using a **scaled unscented transformation** method. Both of them provide high **accuracy** and low **latency** results. Their implementation is quite **power hungry** and the algorithms are quite **complex**. However, it is **cost effective** and the proposals are **scalable** as well. The results are taken from a simulation where not many **communication channels** where used, since it refers only a cellular network, and the **network size** from the simulation is quite inadequate. Finally, there is **no reference** concerning its use on **indoor** or **outdoor** application.

→ Evaluating [18]:

This approach integrates lots of hardware. In this paper, there is a real-time locating system that is applied to Internet of Things (IoT). The system is promising concerning **scalability**. Furthermore, its extremely high **accuracy** and low **latency** are making the approach able to be implemented on the **real-time** applications, both on **indoor** as well as **outdoor** environments. Moreover, since there are many kinds of sensors used, many **communication channels** can be utilized, however this expansion of communication channels is left for future work. The **network size** was rather small, however, this issue is scalable. Last but not least, implementing this approach is very **cost** effective and affordable. Finally, the **power consumption** is very low and **complexity** of the algorithms used is accessible.

→ Evaluation of [19]:

In this paper, the approach is about a combination of the least square methods and the Hybrid Unified Kalman Tracking (HUKT) algorithms integrated with an algorithm based on time of arrival (TOA) and time difference of arrival (TDOA) to achieve high precision tracking. However, neither **accuracy** nor **latency** results are as expected, yet, according to the results, the approach has high potentials to be implemented as part of **real-time** applications. Furthermore, many **communication channels** are utilized, and the **network size** is big enough. The approach is quite adequate for **indoor** environments. Last but not least, there is not that much **scalability** as is, since more optimization is required to achieve better results. The **power consumption** regarding the **complex** algorithms that are used is moderate. Finally, implementation **cost** seems to be of average.

→ Evaluating [20]:

In this paper, the presented tracking system is a **"Dynamic Data-Driven Application System (DDDAS)"-enabled Tracking System for mobile devices** (**DTSMD**). Firstly, the **communication channels** that are used to collect data cover a great range and bandwidth, concerning the sensors' scalability. Also, the **accuracy** is quite high, yet **latency** not that low. Furthermore, this approach can be considered as part of **real-time** applications. Moreover, the **network size** of the tested area was more adequate. In continue, despite the fact that the algorithms are quite **complex**, the implementation is **energy efficient** as well as **cost effective**, hence, considering the **scalability** potentials,

this approach is quite efficient. Finally, this proposal can be applied in both **indoor** and **outdoor** territories.

→ Evaluation of [21]:

This proposal is offering high precision localization pipeline which consist of several algorithms. There are several wireless **communication channels** used to collect data from sensors. The tested area was not that big, yet adequate to get trustworthy measurements and results. The algorithm stack is quite **complex**, however, high **accuracy** with low **latency** were achieved. Moreover, considering the latency measurements, this proposal is capable of being part of a **real-time** application. Also, in spite of its complexity, the proposed approach is quite **cost effective**. Furthermore, it can be applied both **indoors** and **outdoors** as well. Finally, scalability is an issue that was not discussed.

→ Evaluation of [22]:

In this approach, the aim is to alert users about activities or interests. **Communication channel** used in order to position alert users is Wi-Fi. In this proposal, however, we make use of beacon technology. Beacons communicate and distribute data via Wi-Fi, so, since IoT (Internet of Things) is involved in this approach, communication channels and testing are quite **scalable**. Yet, the proposal is limited for **indoor** environments. Low **latency** and high **accuracy** make it a **real-time** proposal. The **network size** is quite large, since more than one building can be involved in this application. In spite of being quite **complex**, it seems quite **cost** efficient.

→ Evaluation of [23]:

The main **communication channel** used in this approach is Wi-Fi. The application is concerning **indoor** facilities. It is quite **real-time** with high **accuracy** and low **latency**. However, it needs to be tested in bigger areas with more conflicts and noise, since the **size** of the **tested area** was quite small. No **complexity** analysis was presented, however the data collection and the optimized algorithm seem to be quite complex. As far as **power consumption**, the application is not that power hungry nor energy saving as well. The proposal is certainly **scalable** to more communication channels and larger facilities. The **cost** was not discussed.

→ Evaluation of [24]:

This proposal, is limited in GPS and GSM signals, so, the **communication channels** used are not that many and the **network size** of the tested area was not that huge. However,

despite not having been test for its **accuracy,** the system is responding promptly, thus **latency** seems not an issue. Furthermore, the main purpose is security so the main goal is to alert the user, weather the vehicle is moving and not where it is heading to. This proposal is definitely a **real-time** one. Moreover, **power consumption** is quite low. No **complexity** analysis is presented to be evaluated nor concerning the **cost**. As far as **scalability**, this approach is quite scalable to be used in large areas and to be able to communicate with the terminal in more communication channels, such as Wi-Fi and Bluetooth.

→ Evaluating [25]:

The proposed method was tested to track the movement profile of a lift car. There were some serious obstacles (noise for example) concerning data gathering in high velocities. To make the long story sort, the **communication channels** used were limited to WSN, such as accelerometer and gyroscope, and GPS signals. The **accuracy** was not that high, however the **latency** was very low. The proposal is definitely **real-time** applicable and has medium power consumption. The **cost** of implementing is not that much and considering that the aim is to achieve in-time maintenance of those means of vertical transport, it can be rendered as cost-effective as well. Despite being tested on a lift car, it can be used in almost any means of vertical transport, **indoors** or **outdoors**.

→ Evaluation of [26]:

In this paper the model described is about tracking the nearest free ambulance in the area using global positioning system and bringing it to the person in distress, hence, this is a **real-time** applicable proposal. The **communication channels** used are GPS system and cellular level. **Accuracy** is high, since triangulation using satellite is being applied. **Latency** is not that high, however it depends on the reaction of the people in the ambulance as well. In spite of the fact that this is a **real-time** application targeting smartphones, no reference is made weather the app is **power hungry** or any power optimization technique is proposed. The targeting **network size** should be huge (all around the world), however this would demand high costs for the servers so that they can tackle the data bulk. The **cost** of implementing this proposal seems to be relative to the cost of the hardware used (GPS devices, server(s)). Last but not least, the project is planned to improve its user interface adding features, however no reference concerning its **scalability** nor utilizing more communication channels. Finally, this application can cover **indoor** as well as **outdoor** environments.

5. Proposed Modifications and Experimental Analysis

1.16. Introduction

Approach [11] seems to have almost the most satisfactory results and the Interacting Multiple Model (IMM) modification is something quite helpful. A serious issue is that the approach has not been tested in the field nor expanded for outdoor environments, limiting the results to simulation obtained only. In [11], it is proposed a 2^{nd} – grade HMM with an adaptive Transition Probability Table, according a function that takes into account the corner and the distance of the previous states relatively to the next one. The “replacement modified” optimization is quite contributing combined with the IMM.

1.17. Hidden Markov Model

Let a Hidden Markov Model-based filter [28, pp. 1-8] be used to process the localization data. This is an algorithmic model that uses state estimates in order to provide a transition probability table and figure the final location. The way probabilities as well as state estimates are calculated, is being modified or filtered to achieve better and more efficient results. Hence, the less and more accurate possible states the more optimal results will be. To make the long story short, it seems there are two levels that need optimizations: calculation of the state estimates, both hidden and observations as well, and computing the Transition Probability Table. Moreover, the hidden Markov model (HMM) is a really helpful tool to proceed on concerning **geolocation-based services,** since, it can be applied for **pattern recognition** (in [12] and [13]) to continuously update, upgrading as well, the training part of the applications (machine learning) and with some normalization and modifications on the Transition Probabilities Table, much more accurate results with diminished latency can be achieved.

1.18. Modifications Needed

The already proposed IMM should be modified to become scalable for indoor as well as outdoor environments and real-time applications. Latency is a parameter that needs to be lessened and a constant training algorithm should be established to search for any tracking paths that may follow specific patterns. Furthermore, no area information is being used. Such data seems quite essential for the optimization of the localization, since they can alter the way of tracking in a more "logical" way to minimize the number of computational errors based on transition probabilities.

1.19. Proposal

To begin with, having more accurate measurements, is meaning more **data resources**. Regarding indoor environments, the is quite much conflict between the signals due to the congestion of too many mobile devices inside an area. Bluetooth receivers, signal MIMO antennas and Wi-Fi access points should be considered significantly as DATA access points, since the mobile cellular signal by itself will not be that accurate, considering the NLOS error under such circumstances. Moreover, each device has a **signature**. This can indicate a "**user**" of the tracking system. The system should have **layers**. Each **layer** should represent a different **domain** of the area where it is applied. Every "**user**" changing a domain will have his **tracking information** connected to him and until "logging out" of the system, his **real-time tracking information** will be available. The challenge might be to combine mobile **device signature** with **identity recognition**, however, this will imply serious privacy issues, such as somehow searching by the device's signature the owner's account or google/apple account login to access the regional Wi-Fi, for example, or even gain access to security or traffic cameras.

Finally, to acquire better accuracy results as well as to achieve a tracking normalization, "**knowledge of the area**" can be considered vital information. Geomorphological information will help to prevent tracking paths that cannot logically exist or, in case such tracking activity may exist, to identify possible accidents. In addition, the knowing how an area is constructed, hence, being able to identify obstacles or shortcuts during a tracking session, will improve the prediction of the tracking route, meaning less accuracy errors. This would be a model that will use some parameters and

and constants which will interact with the way that the Transition Probabilities table will be created and optimize the results. A pattern recognition model will be obtaining the tracking results and this will provide us constantly updated normalization. Summing up, this proposal is presenting a theoretical model in which a **combination** is implied of the already improved **HMM** with the **IMM** of [11] **improved** additionally with a novel **Map-aware model** which can be additionally trained with robust **pattern recognition scheme** in order to achieve **normalization**.

1.20. Model Definition

In this section, a mathematical definition of the proposed model will be presented in a theoretical level. To begin with, the Bayesian-HMM is parted of the Initial states, and there are the hidden states (x(t)) and the observations (y(t)); assuming N hidden states, V distinct observation symbols for each state and T observations. Also, there is the Transition Probability Table (**TPT**), which concerns the probabilities of switching from a hidden state to another. However, there are transition probabilities from a hidden state to another ($\phi_{i=1..N,j=1..V}$), as well as that a hidden state observes an observation ($\theta_{i=1..N,j=1..N}$); of course both Φ_i and Θ_i must sum to 1. Both states, hidden as well as observations, are relevant to time and their values do follow a distribution. $X_t \sim D_N(\beta)$ and $Y_t \sim D_v(\alpha)$, ($D_n(o)$ is not representing a specific distribution) are relevant to the hyperparameters β and α respectively. Thus, changing the hyperparameters' value means interfering with the **entropy** of the probabilities. Specifically, to alter the observations distribution's entropy, we need to modify the observation symbols' distribution (Θ_i). Moreover, to achieve tracking **normalization**, the **hyperparameter's β value**, that controls the density of the Transition Probablility Table, needs to be significantly lowered below 1, having as a result the next states to be highly predictable. However, that value will be **changing** according the feedback of the **Pattern Recognition Scheme** and **terrain data**, processed by the map-aware model, combined with the results from the IMM. Furthermore, the map-aware-model will provide data that will nullify transition probabilities to a not feasible, according to the terrain, state. The idea of this model is to alter the **TPT** that was researched in [11], using data from the map-aware model and nullifying some probabilities that refer to states that are not viable. In order to make this process efficient, the map-aware model will be held responsible for

filtering the hidden and observation states as well. If a state is not viable, it will not be considered, hence less states will produce more accurate and faster results. Last but not least, the model will try to be simplified, filtering the initial state ($\pi=P(x_0)$) with the map-aware model and applying the Maximum Likelihood Estimate, in case there is noise that cannot track an exact position. Finally, regarding **noise filtering**, the Gaussian-based model will be followed.

1.20.1. The Location variable

The **TPT**, as researched in [11], will be **divided** in two parts; Position Transition Probability (**PTP**) and Sight Transition Probability (**STP**). When **not in sight**, the map-aware model, will be an improvement, **limiting** the **possible position transition states**. In addition to this, the **IMM**, by processing the velocity data, will result to a more **normalized** tracking path, than the one without map-aware model filtering. The velocity processing is quite simple, since the states are accelerating and decelerating, however, the tracking information that will be provided needs should be filtered, relevantly to the terrain information. For example, if the velocity is quite high and the subject is reaching an obstacle that might crash on, the map aware model will proceed on a normalized tracking according to the terrain, but the IMM will assume the location according to the high speed. In this case there are two different position-state families. This is a conflict that needs to be optimized. The map-aware model will return the dismissed position state as a possible state in the hidden states distribution for the next computing to take into account the possibility that the subject has deviated from the the terrain-aware route.

1.21. Flow Chart

In this section there will be presented a flow chart. This represents the way the HMM will be modified to achieve the desired optimization. The Hidden Markov Model, already optimized and with the IMM, will have another intervention before the output of the Transition Probability Table, elimination abnormal paths, minimizing the transition probabilities to them. After the final state are calculated, data from the existing Transition Probability Table as well as the final states will be used from the

pattern recognition scheme to train the system for abnormal routes and achieve an efficient normalization. The Pattern recognition scheme will have as inputs the initial states as well. This will help the system not to dismiss abnormalities in tracking paths but to use them as initial possible states, in order to identify peculiar routes or locations.

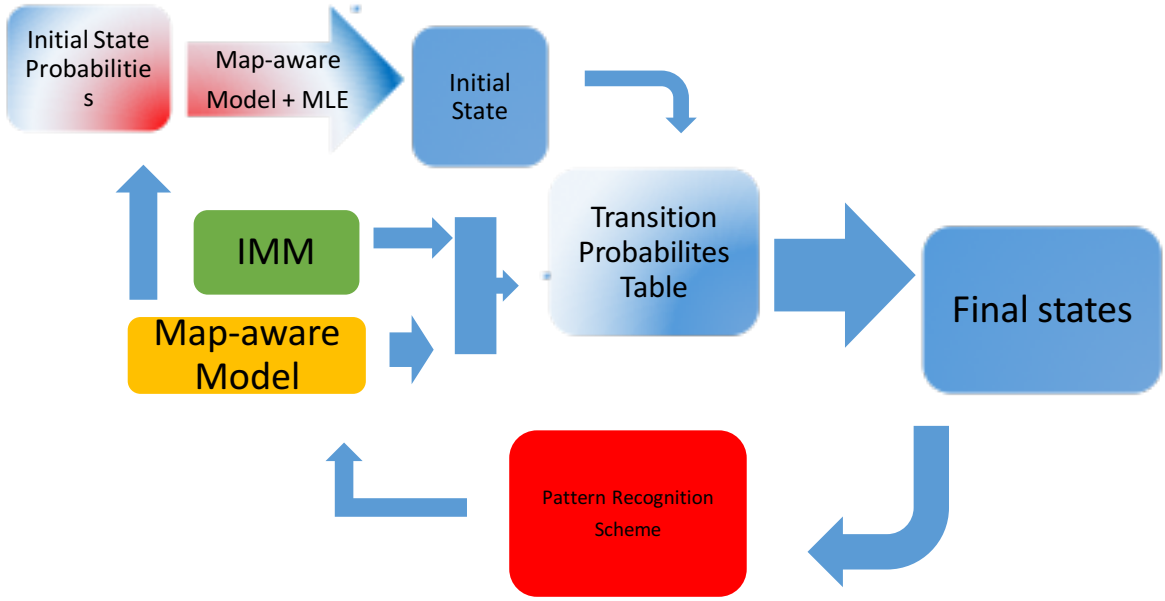


Figure 1: Proposed Modified model

In figure 1, obtaining the initial state can be optimized using the Maximum Likelihood Estimate (MLE) based on the Map aware model to prevent not feasible location. In continue, Transition Probability Table needs to be calculated. Observation probabilities needed, will be sensitive to parameters calculated from the IMM and the proposed model, thus, more accurate measurements will occur. Moreover, considering the initial state as input, the pattern recognition scheme will "train" the software to

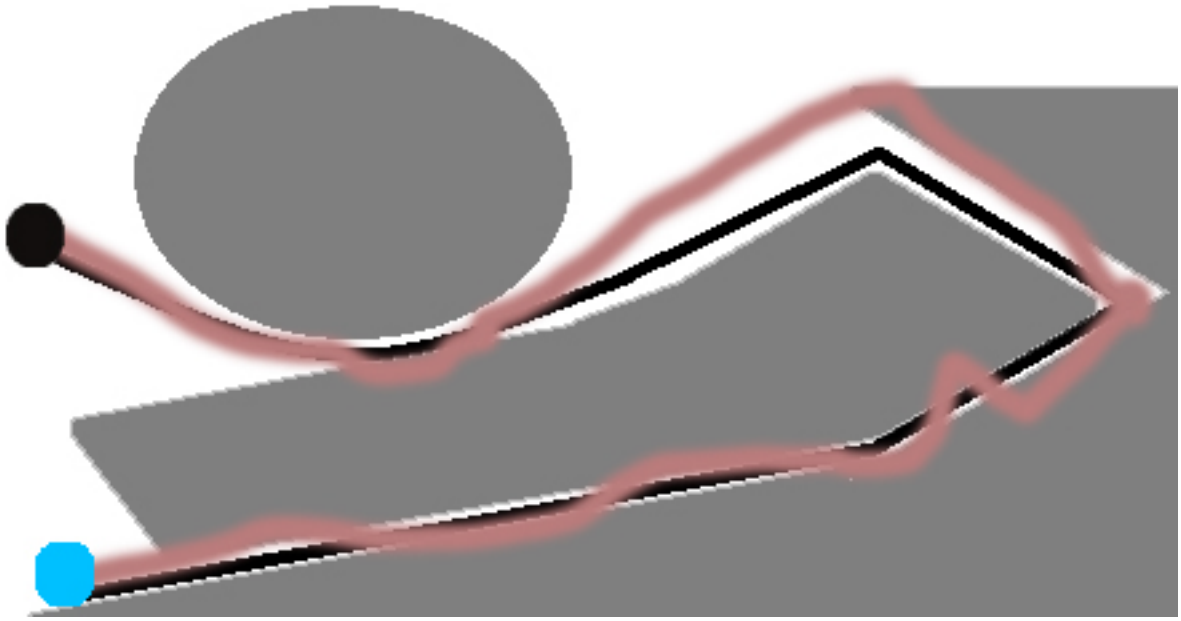
identify abnormal paths. This can provide normalization to the whole model, however, it is not wise to exclude such tracking information, since sometimes it may exist. In the latter case, more research needs to be done over normalization algorithms.

1.22. Comparative Visualization

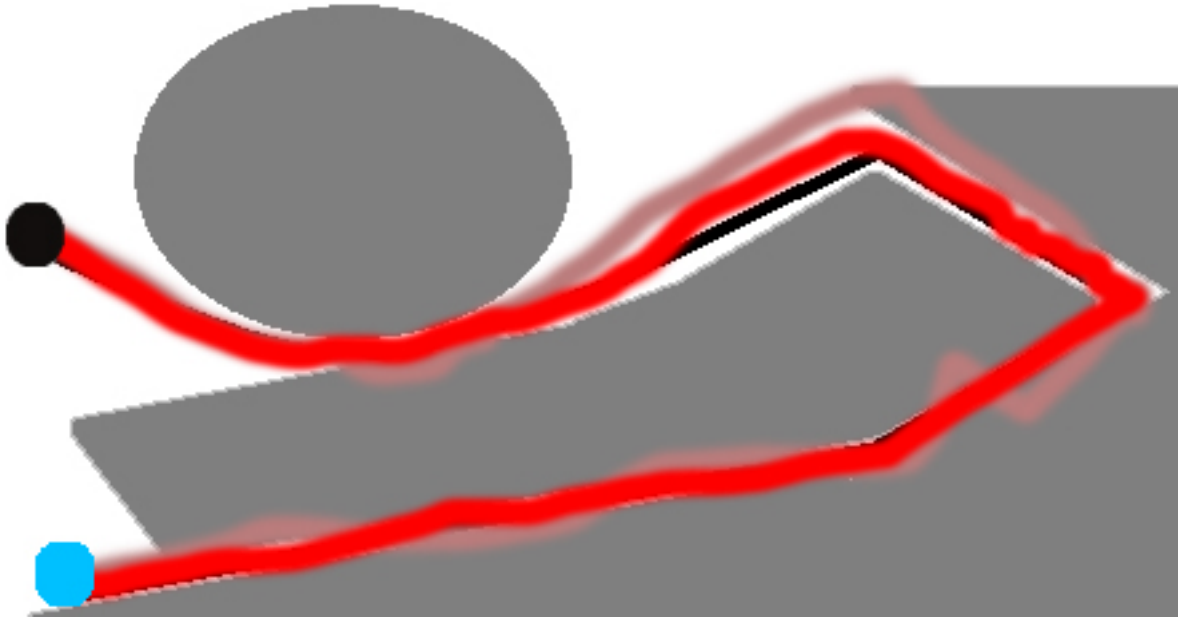
In this section there is a visualization of the desired tracking result after the proposed optimization. The scenario is about an outdoor are where there are obstacles and the mobile node is moving from the black point to the teal. The node is always accelerating as much as possible and decelerating harshly to provide difficult circumstances for the IMM. In picture 2 you can see the real route:

Picture 2: Actual route

The following pictures represent the desired result of the proposed optimization in comparison to the proposed that will be modified. Picture 3 represents the IMM (Figure 2) modification and picture 4 is an ideal preview of the proposal's result (Figure 6).



Picture 3 HMM-based tracking route



Picture 4: Proposed model's estimate optimization

The Map awareness when calculating the Transition Probability Table will provide us much more accurate results and help us lessen even more the error of NLOS environments.

1.23. Model summary

The HMM modified by the IMM flow chart is presented in Figure 2. The presented model has 3 optimizations. The initial state will be calculated, to prevent noise errors, by using the Maximum Likelihood Estimate(MLE) modified be the map-aware model.

This will exclude locations that are not feasible (Figure 3). Achieving such an optimization is of high value to the project, since knowing the initial location of the subject tracked is quite important, even more when the tracking procedures are about to be scaled with real-time identification of the subject. Furthermore, optimization is needed regarding the tracking accuracy of the model. There are common errors in location positioning models that can produce quite abnormal results, such the on in picture 3, trying to create a continuous tracking path. Those models, however, lack of map awareness, which seems quite essential when tracking a subject in a 3D environment. The proposed model's goal is to achieve a map-aware tracking, so that location estimates can be improved and even normalized to achieve better latency results.

The proposed model Flow Chart is presented in Figure 4. There are two parts on this model. The **computing part** and the **learning part**. The first part, is about calculating the Transition Probability Table of the Hidden Markov Model interfering with the **entropy** of the HMM, modifying the **observation symbols** according to the map aware-model. Meanwhile, the Transition Probability Table will be modified by the already proposed Interacting Multiple Model (IMM) as well. Hence accuracy will dramatically improve, since location **final states** (final location estimates) will be **feasible**, according to the **area morphology**. Moreover, along with this part, the model will be "learning" from the pattern recognition scheme. In this **learning part**, the scheme will be using the final state location estimates in order to achieve a **normalization** concerning tracking paths as well as location estimates, meaning, additionally, transition probabilities. That scheme will extract data that will continuously update the transition probability computing and will be filtered through the map-aware model. It is quite essential to highlight that this scheme will update and train the system only after it will have enough data to extract some results, since it is a data mining procedure. Thus, updating will be happening, however, not in a way that will interfere with system's performance. To make the long story short, the pattern recognition scheme is the part of the model that will be held responsible for the normalization of locating and tracking, hence it cannot be used a tool until it will become useful. To achieve such data mining will demand time, but after trained, it will provide quite an efficient tool.

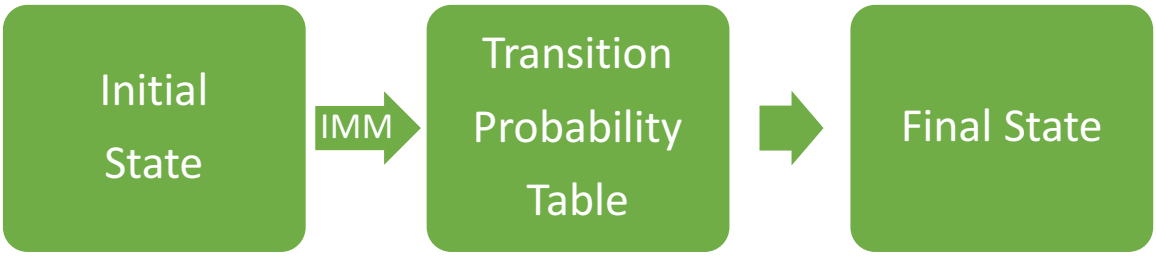


Figure 2: Proposed model on [11]

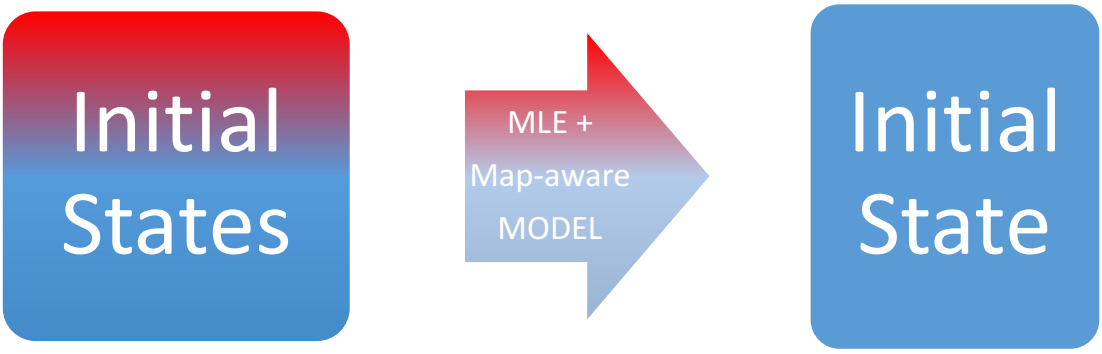


Figure 3: Initial State Estimate Modification Flow Chart

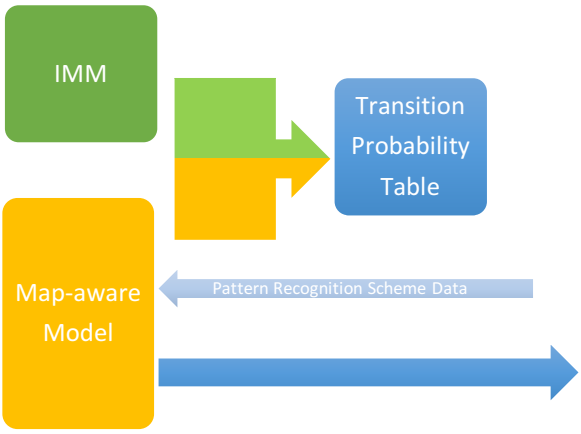


Figure 4: Transition Probability Table Computing Modification Flow Chart

Figure 5: Pattern Recognition Scheme Flow Chart

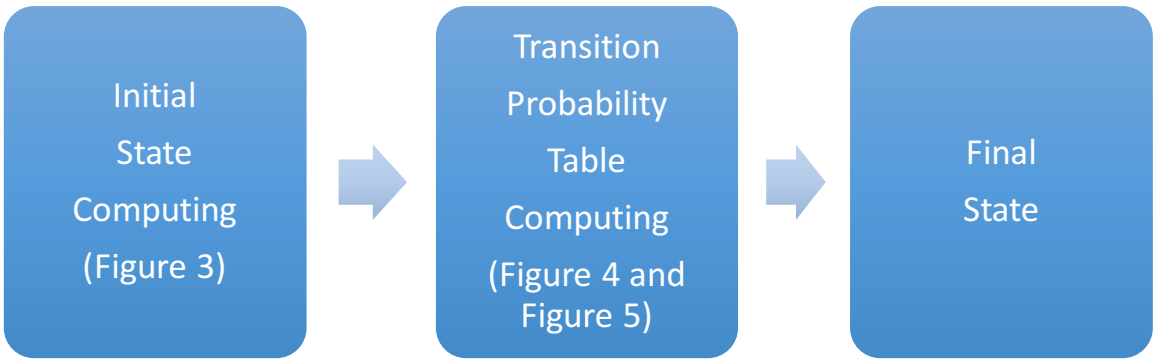


Figure 6: Summing up Flow Charts

1.24. Scalability

The model will be quite scalable. To begin with, layer parting of the area, in which locating and tracking is taking place, will help the big data issue of subjects' information, yet data will be transferred to a server where the pattern recognition scheme will be proceeding with data mining. Concerning **communication channels** it can utilize as many as possible to obtain the acquired data and it will be designed to be efficient for huge **networks**. Furthermore, **accuracy** as well as **latency** are about to be dramatically improved. Moreover, this is a research concerning a **real-time** model. **Power consumption** of the system and **complexity** of the algorithm will be some of the main pivots around which the model will be researched.

1.25. Experimental results

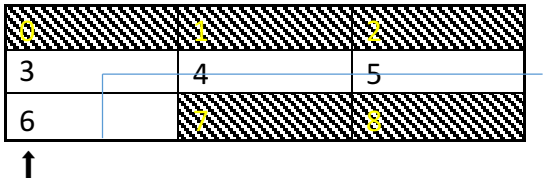
Let a subject be moving from block 6 to 5 (Picture 2). The assumptions that will be followed are:

→the subject can move one block at a time moment or with a very slight chance to stand still.

→noise will be introduced to the system (we can see the noise transition probabilities in Table 2)

Table 2: Noise Transition Probabilities

Pij	0	1	2	3	4	5	6	7	8
0	0.05	0.3	0.01	0.3	0.3	0.01	0.01	0.01	0.01
1	0.15	0.12	0.15	0.15	0.25	0.15	0.01	0.01	0.01
2	0.01	0.25	0.05	0.01	0.25	0.4	0.01	0.01	0.01
3	0.2	0.1	0.01	0.07	0.3	0.01	0.2	0.1	0.01
4	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
5	0.01	0.1	0.2	0.01	0.3	0.07	0.01	0.1	0.2
6	0.01	0.01	0.01	0.4	0.3	0.01	0.05	0.20	0.01
7	0.01	0.01	0.01	0.15	0.25	0.15	0.15	0.12	0.15
8	0.01	0.01	0.01	0.01	0.25	0.4	0.01	0.25	0.05



Picture 5: Experimental case (6→1)

Java code was used to implement the HMM and conduct the experiment. The actual and the noise measurements can be seen in table 3.

Table 3: Measurements

Actual	Noise
6	6
3	0
4	1
5	8

According to the HMM, which is not terrain aware, the Transition Probability Table can be formed as seen in Table 4. However, the proposed scheme will provide the transition Probability Table of Table 5.

Table 4: TPT_1

Pij	0	1	2	3	4	5	6	7	8
0	0.1	0.4	0	0.4	0.1	0	0	0	0
1	0.3	0.02	0.3	0.04	0.3	0.04	0	0	0
2	0	0.4	0.1	0	0.1	0.4	0	0	0
3	0.3	0.04	0	0.02	0.3	0	0.3	0.04	0
4	0.04	0.2	0.04	0.2	0.04	0.2	0.04	0.2	0.4
5	0	0.04	0.3	0	0.3	0.02	0	0.04	0.3
6	0	0	0	0.4	0.1	0	0.1	0.4	0
7	0	0	0	0.04	0.3	0.04	0.3	0.02	0.3
8	0	0	0	0	0.1	0.4	0	0.4	0.1

Table 5: TPT_2

Pij	0	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0.2	0.4	0	0.4	0	0
4	0	0	0	0.4	0.1	0.4	0.1	0	0
5	0	0	0	0	0.7	0.3	0	0	0
6	0	0	0	0.7	0.1	0	0.2	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0

1.25.1. Results

After running the experiment, the results are shown in the following table (table 6: results)

Table 6: Results

RESULTS	measurements deviation	runtime
initial	2.25	not applied
HMM	1.5	2.418
ma_HMM	0.5	1.887
V_HMM	1.5	0.056
V_ma-HMM	0.5	0.054

table 6 legend:

HMM: hidden Markov Model
ma-: map-aware optimization
V_: using the Viterbi optimization

As can be seen, there is a 300% less deviation using the map-aware model. Moreover, latency is dramatically decreased. The results are acquired 80% faster than the basic ones from the basic-HMM and using the Viterbi optimization the map-aware model still provides them 9.7% faster.

1.25.2. Summary

To sum up, it is obvious the the results are quite more accurate and the latency is less as well. However, this experiment is about a static Transition Probability Table, which will be calculated according to the map-aware model. The IMM modification will imply a 2^{nd}-grade HMM and a function, as referred in [11], for an adaptive TPT, however, designing this, will be future work. Yet, the results are far better than the existing model.

6. Future Work – Conclusion

1.26. Future Work

This proposal is based on my personal evaluation of the approaches I studied above. More time is needed to create and apply the proposed models on a new scheme, creating a robust algorithmic model. Meanwhile optimizations will be studied over the [11] and even some combinations with other approaches such as [14] and [22]. Concerning outdoor environments, more research need to be done so that the signature is not lost due to conflicts and noise. Applying the model may require an application which will be part of routers' firmware or firewall, or even a special modification in mobile network or Bluetooth antennas to obtain such data. Finally, a normalization of the pattern recognition should be studied to identify abnormal tracking information and either investigate them or be considered as algorithm's deviation errors, and meanwhile, experimental analysis will be conducted to test the model. Scaling the model to a user-friendly app for on-the-go access will be considered as well.

1.27. Conclusion

In conclusion, after a brief introduction to Location Based services, the localization and tracking problem is presented. Obviously, nowadays, being able not only to track, but to predict the following route as well, is a matter of great concern. The objective of this project is to conduct a quality evaluation of proposed approaches and models to cure this challenging issue. The project's methodology is document-driven since I studied related works and evaluated them based on their publications and contributions. There is a section where an analysis is presented of all the methodology used to complete the project. The evaluation is based on specific challenging criteria and is visualized in a comparative table and analysed as well. In continue, a novel approach of a robust and promising model is presented. That theoretical model is a HMM-based one and it is a combination of a novel map-aware model with the proposal described in [11], enhanced with a pattern recognition scheme to achieve normalization, combining the localization and tracking model with the data mining. To be tested for its

viability, a simplified map-aware filter based on its logic was implemented in a simulation using Java code in Eclipse and the results were quite promising for its development. That model is supposed to be developed in order to meet the criteria used for the evaluation and with the potential to being implemented as an on-the-go application for system superusers.

Summing up, the map-aware model will affect the Transition Probability Table. However, the goal is to combine it with the already proposed Interacting Multiple Model [11]. The latter optimises the results of the Hidden Markov Model by affecting the observation symbols with the nodes' velocity parameter. Despite, the results still can deviate from the feasible pathways of the area, hence results may be abnormal locations. By optimizing the observation probabilities with an "area/map aware" filter, faster and more accurate results can be obtained. The term faster sounds quite weird, since one more filter is to be applied while computing is not over yet, however, with this model we can achieve continuous normalization on tracking routes and train the model. This will not only end up in achieving lower latency, but will indicate peculiar location that deviate from the normalized ones.

7. References

In this section there are the document resources that were used on this Thesis, however, some term definitions where acquired from Wikipedia. However, since Wikipedia is quite unreliable, they were double checked and even corrected by notes from lectures and courses I attended, in order to expand my knowledge over this scientific sector. The referencing system used is the IEEE one.

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Appendix A

Java Code for basic-HMM filter:

```
1 package Markov;
2
3 //package sensor_fusion;
4 import java.awt.Color;
5 import java.awt.Graphics;
6 import java.awt.Image;
7 import java.io.File;
8 import java.io.FileReader;
9 import java.io.IOException;
10    import java.io.LineNumberReader;
11    import java.util.Arrays;
12    import java.util.StringTokenizer;
13
14    import javax.swing.JFileChooser;
15    import javax.swing.JMenuBar;
16    import javax.swing.JOptionPane;
17
18    @SuppressWarnings("serial")
19    public class HMMFilter extends javax.swing.JFrame {
20
21        int num_states = 9; //The number of possible states
22        final int menubar_height = 50;
23        int num_measurements = 0;  // how many measurements I have s
      tored so far
24        int[] real_measurements;   // the actual mesurements
25        int[] noise_measurements;   // the 'noise' measurements
26        int[] HMM_measurements;     // the calculated filter values

27        int[][] best_path; //shows the previous neighbour in the bes
      t HMM path
28        double[][] transition_probabilities; //HMM model transition
      probability
29        double[][] state_probabilities; //HMM model state probabilit
      y
30        double[][] noise_probabilities; // Input noise data structur
      e
```

```
31          double max_value;
32          int file_opened=0;
33          int width, height;
34          int toggled=0;
35          Image backbuffer;
36          Graphics screen;
37
38          /** Creates new form HMMFilter */
39          public HMMFilter() {
40              initComponents();
41
42              real_measurements = new int[4];   // αρχικοποιήσεις
43              noise_measurements = new int[4];
44              HMM_measurements = new int[4];
45              best_path=new int[num_states][4];
46              transition_probabilities=new double[num_states][num_stat
    es];
47              state_probabilities=new double[num_states][4];
48              noise_probabilities=new double[num_states][num_states];

49
50              setSize(500,400);
51              width= getSize().width;
52              height=getSize().height;
53
54              backbuffer = createImage(width, height);
55              screen = backbuffer.getGraphics();
56              screen.setColor(Color.white);
57              screen.fillRect(0, 0, width, height);
58              screen.setColor(Color.black);
59
60
61          }
62
63          /** This method is called from within the constructor to
64           * initialize the form.
65           * WARNING: Do NOT modify this code. The content of this met
    hod is
66           * always regenerated by the Form Editor.
67           */
68          @SuppressWarnings("unchecked")
69          // <editor-
    fold defaultstate="collapsed" desc="Generated Code">//GEN-
```

```
    BEGIN:initComponents
70      private void initComponents() {
71
72          jDialog1 = new javax.swing.JDialog();
73          jButton1 = new javax.swing.JButton();
74          jButton4 = new javax.swing.JButton();
75          jScrollPane1 = new javax.swing.JScrollPane();
76          jTable1 = new javax.swing.JTable();
77          jButton2 = new javax.swing.JButton();
78          jCheckBox1 = new javax.swing.JCheckBox();
79          jFileChooser1 = new javax.swing.JFileChooser();
80          jPanel1 = new javax.swing.JPanel();
81          jInternalFrame1 = new javax.swing.JInternalFrame();
82          fileChooser = new javax.swing.JFileChooser();
83          jDialog2 = new javax.swing.JDialog();
84          jButton5 = new javax.swing.JButton();
85          jButton8 = new javax.swing.JButton();
86          jScrollPane2 = new javax.swing.JScrollPane();
87          jTable2 = new javax.swing.JTable();
88          jDialog3 = new javax.swing.JDialog();
89          jLabel5 = new javax.swing.JLabel();
90          jButton3 = new javax.swing.JButton();
91          jLabel2 = new javax.swing.JLabel();
92          jLabel1 = new javax.swing.JLabel();
93          jLabel3 = new javax.swing.JLabel();
94          jLabel4 = new javax.swing.JLabel();
95          jMenuBar1 = new javax.swing.JMenuBar();
96          jMenu1 = new javax.swing.JMenu();
97          miOpen = new javax.swing.JMenuItem();
98          miDeviation = new javax.swing.JMenuItem();
99          miNoise = new javax.swing.JMenuItem();
100         HMMParameters = new javax.swing.JMenuItem();
101         miClose = new javax.swing.JMenuItem();
102
103         jButton1.setText("OK&Close");
104         jButton1.addActionListener(new java.awt.event.ActionList
    ener() {
105             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
106                 jButton1ActionPerformed(evt);
107             }
108         });
109
```

```
110         jButton4.setText("Close");
111         jButton4.addActionListener(new java.awt.event.ActionList
    ener() {
112             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
113                 jButton4ActionPerformed(evt);
114             }
115         });
116 
117         jTable1.setModel(new javax.swing.table.DefaultTableModel
    ( //transition probability table
118             new Object [][] {
119                     {"0",  new Float(0.1),  new Float(0.4),  new
    Float(0.0),  new Float(0.04),  new Float(0.01), new Float(0.0),
    new Float(0.0),  new Float(0.0),  new Float(0)},
120                     {"1",  new Float(0.3),  new Float(0.02),  ne
    w Float(0.3),  new Float(0.04),  new Float(0.3), new Float(0.04)
    ,  new Float(0.0),  new Float(0.0),  new Float(0.0)},
121                     {"2",  new Float(0.0),  new Float(0.4),  new
    Float(0.1),  new Float(0.0),  new Float(0.1), new Float(0.4),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)},
122                     {"3",  new Float(0.3),  new Float(0.04),  ne
    w Float(0.0),  new Float(0.02),  new Float(0.3), new Float(0.0),
     new Float(0.3),  new Float(0.04),  new Float(0.0)},
123                     {"4",  new Float(0.04),  new Float(0.2),  ne
    w Float(0.04),  new Float(0.2),  new Float(0.04), new Float(0.2)
    ,  new Float(0.04),  new Float(0.2),  new Float(0.04)},
124                     {"5",  new Float(0.0),  new Float(0.04),  ne
    w Float(0.3),  new Float(0.0),  new Float(0.3), new Float(0.02),
     new Float(0.0),  new Float(0.02),  new Float(0.3)},
125                     {"6",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.4),  new Float(0.1), new Float(0.0),  n
    ew Float(0.1),  new Float(0.4),  new Float(0.0)},
126                     {"7",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.04),  new Float(0.3), new Float(0.04),
    new Float(0.3),  new Float(0.02),  new Float(0.3)},
127                     {"8",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.1), new Float(0.4),  n
    ew Float(0.0),  new Float(0.4),  new Float(0.01)}
128             },
129 
130 
131             new String [] {
```

```
132                     "    Pij", "      0","     1", "     2", "
    3", "     4", "     5", "     6", "     7", "     8"
133             }
134         ) {
135             Class[] types = new Class [] {
136                     java.lang.String.class, java.lang.Float.clas
    s, java.lang.Float.class, java.lang.Float.class, java.lang.Float
    .class, java.lang.Float.class, java.lang.Float.class, java.lang.
    Float.class, java.lang.Float.class, java.lang.Float.class
137                     };
138 
139             public Class getColumnClass(int columnIndex) {
140                 return types [columnIndex];
141             }
142         });
143         jScrollPane1.setViewportView(jTable1);
144         jTable1.getColumnModel().getColumn(0).setResizable(true)
    ;
145 
146         jButton2.setText("OK&Filter");
147         jButton2.addActionListener(new java.awt.event.ActionList
    ener() {
148             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
149                 jButton2ActionPerformed(evt);
150             }
151         });
152 
153         jCheckBox1.setText("Use Viterbi decoding");
154 
155         javax.swing.GroupLayout jDialog1Layout = new javax.swing
    .GroupLayout(jDialog1.getContentPane());
156         jDialog1.getContentPane().setLayout(jDialog1Layout);
157         jDialog1Layout.setHorizontalGroup(
158             jDialog1Layout.createParallelGroup(javax.swing.Group
    Layout.Alignment.LEADING)
159             .addGroup(jDialog1Layout.createSequentialGroup()
160                 .addContainerGap()
161                 .addGroup(jDialog1Layout.createParallelGroup(jav
    ax.swing.GroupLayout.Alignment.LEADING)
162                     .addComponent(jScrollPane1, javax.swing.Grou
    pLayout.Alignment.TRAILING)
163                     .addGroup(jDialog1Layout.createSequentialGro
```

```
up()
164                         .addComponent(jButton1)
165                         .addGap(106, 106, 106)
166                         .addComponent(jButton2)
167                         .addPreferredGap(javax.swing.LayoutStyle
.ComponentPlacement.RELATED, javax.swing.GroupLayout.DEFAULT_SIZ
E, Short.MAX_VALUE)
168                         .addComponent(jButton4)))
169                 .addContainerGap())
170             .addGroup(jDialog1Layout.createSequentialGroup()
171                 .addGap(173, 173, 173)
172                 .addComponent(jCheckBox1)
173                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
_SIZE, Short.MAX_VALUE))
174         );
175         jDialog1Layout.setVerticalGroup(
176             jDialog1Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
177             .addGroup(jDialog1Layout.createSequentialGroup()
178                 .addContainerGap()
179                 .addComponent(jScrollPane1, javax.swing.GroupLay
out.PREFERRED_SIZE, 109, javax.swing.GroupLayout.PREFERRED_SIZE)

180                 .addGap(18, 18, 18)
181                 .addComponent(jCheckBox1)
182                 .addPreferredGap(javax.swing.LayoutStyle.Compone
ntPlacement.UNRELATED)
183                 .addGroup(jDialog1Layout.createParallelGroup(jav
ax.swing.GroupLayout.Alignment.BASELINE)
184                     .addComponent(jButton4)
185                     .addComponent(jButton1)
186                     .addComponent(jButton2))
187                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
_SIZE, Short.MAX_VALUE))
188         );
189 
190         javax.swing.GroupLayout jPanel1Layout = new javax.swing.
GroupLayout(jPanel1);
191         jPanel1.setLayout(jPanel1Layout);
192         jPanel1Layout.setHorizontalGroup(
193             jPanel1Layout.createParallelGroup(javax.swing.GroupL
ayout.Alignment.LEADING)
194             .addGap(0, 100, Short.MAX_VALUE)
```

```
195         );
196         jPanel1Layout.setVerticalGroup(
197             jPanel1Layout.createParallelGroup(javax.swing.GroupL
    ayout.Alignment.LEADING)
198             .addGap(0, 100, Short.MAX_VALUE)
199         );
200 
201         jInternalFrame1.setVisible(true);
202 
203         fileChooser.addActionListener(new java.awt.event.ActionL
    istener() {
204             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
205                 fileChooserActionPerformed(evt);
206             }
207         });
208 
209         javax.swing.GroupLayout jInternalFrame1Layout = new java
    x.swing.GroupLayout(jInternalFrame1.getContentPane());
210         jInternalFrame1.getContentPane().setLayout(jInternalFram
    e1Layout);
211         jInternalFrame1Layout.setHorizontalGroup(
212             jInternalFrame1Layout.createParallelGroup(javax.swin
    g.GroupLayout.Alignment.LEADING)
213             .addGroup(jInternalFrame1Layout.createSequentialGrou
    p()
214                 .addContainerGap()
215                 .addComponent(fileChooser, javax.swing.GroupLayo
    ut.PREFERRED_SIZE, javax.swing.GroupLayout.DEFAULT_SIZE, javax.s
    wing.GroupLayout.PREFERRED_SIZE)
216                 .addContainerGap())
217         );
218         jInternalFrame1Layout.setVerticalGroup(
219             jInternalFrame1Layout.createParallelGroup(javax.swin
    g.GroupLayout.Alignment.LEADING)
220             .addGroup(jInternalFrame1Layout.createSequentialGrou
    p()
221                 .addContainerGap()
222                 .addComponent(fileChooser, javax.swing.GroupLayo
    ut.PREFERRED_SIZE, 256, javax.swing.GroupLayout.PREFERRED_SIZE)

223                 .addContainerGap())
224         );
```

```
225
226         jButton5.setText("OK&Close");
227         jButton5.addActionListener(new java.awt.event.ActionList
    ener() {
228             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
229                 jButton5ActionPerformed(evt);
230             }
231         });
232
233         jButton8.setText("Close");
234         jButton8.addActionListener(new java.awt.event.ActionList
    ener() {
235             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
236                 jButton8ActionPerformed(evt);
237             }
238         });
239
240         jTable2.setModel(new javax.swing.table.DefaultTableModel
    (   //noise probability table
241                 new Object [][] {
242                         {"0",  new Float(0.05),  new Float(0.3),
    new Float(0.01),  new Float(0.3),  new Float(0.3),  new Float(0.
    01),  new Float(0.01),  new Float(0.01),  new Float(0.01)},
243                         {"1",  new Float(0.15),  new Float(0.12)
    ,  new Float(0.15),  new Float(0.15),  new Float(0.15),  new Flo
    at(0.15),  new Float(0.01),  new Float(0.01),  new Float(0.01)},

244                         {"2",  new Float(0.01),  new Float(0.25)
    ,  new Float(0.05),  new Float(0.01),  new Float(0.01),  new Flo
    at(0.4),  new Float(0.01),  new Float(0.01),  new Float(0.01)},

245                         {"3",  new Float(0.2),  new Float(0.1),
    new Float(0.01),  new Float(0.07),  new Float(0.07),  new Float(
    0.01),  new Float(0.2),  new Float(0.1),  new Float(0.01)},
246                         {"4",  new Float(0.1),  new Float(0.1),
    new Float(0.1),  new Float(0.1),  new Float(0.1),  new Float(0.2
    ),  new Float(0.1),  new Float(0.1),  new Float(0.1)},
247                         {"5",  new Float(0.01),  new Float(0.1),
    new Float(0.2),  new Float(0.01),  new Float(0.01),  new Float(0
    .07),  new Float(0.01),  new Float(0.1),  new Float(0.2)},
248                         {"6",  new Float(0.01),  new Float(0.01)
```

```
, new Float(0.01), new Float(0.4), new Float(0.4), new Float
(0.01), new Float(0.05), new Float(0.2), new Float(0.01)},
                        {"7", new Float(0.01), new Float(0.01)
, new Float(0.01), new Float(0.15), new Float(0.15), new Flo
at(0.15), new Float(0.15), new Float(0.12), new Float(0.15)},

                        {"8", new Float(0.01), new Float(0.01)
, new Float(0.01), new Float(0.01), new Float(0.01), new Flo
at(0.4), new Float(0.01), new Float(0.25), new Float(0.05)}
                },
            new String [] {
                "    Pij", "      0","     1", "     2", "     3
", "     4", "     5", "     6", "     7", "     8"
            }
        ) {
            Class[] types = new Class [] {
                    java.lang.String.class, java.lang.Float.clas
s, java.lang.Float.class, java.lang.Float.class, java.lang.Float
.class, java.lang.Float.class, java.lang.Float.class, java.lang.
Float.class, java.lang.Float.class, java.lang.Float.class
                    };

            public Class getColumnClass(int columnIndex) {
                return types [columnIndex];
            }
        });
        jScrollPane2.setViewportView(jTable2);
        jTable2.getColumnModel().getColumn(0).setResizable(true)
;

        javax.swing.GroupLayout jDialog2Layout = new javax.swing
.GroupLayout(jDialog2.getContentPane());
        jDialog2.getContentPane().setLayout(jDialog2Layout);
        jDialog2Layout.setHorizontalGroup(
            jDialog2Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
            .addGroup(jDialog2Layout.createSequentialGroup()
                .addContainerGap()
                .addGroup(jDialog2Layout.createParallelGroup(jav
ax.swing.GroupLayout.Alignment.LEADING)
                    .addComponent(jScrollPane2, javax.swing.Grou
pLayout.Alignment.TRAILING)
                    .addGroup(jDialog2Layout.createSequentialGro
```

```
up()
276                         .addComponent(jButton5)
277                         .addPreferredGap(javax.swing.LayoutStyle
.ComponentPlacement.RELATED, javax.swing.GroupLayout.DEFAULT_SIZ
E, Short.MAX_VALUE)
278                         .addComponent(jButton8)))
279                 .addContainerGap())
280         );
281         jDialog2Layout.setVerticalGroup(
282             jDialog2Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
283             .addGroup(jDialog2Layout.createSequentialGroup()
284                 .addContainerGap()
285                 .addComponent(jScrollPane2, javax.swing.GroupLay
out.PREFERRED_SIZE, 109, javax.swing.GroupLayout.PREFERRED_SIZE)

286                 .addGap(48, 48, 48)
287                 .addGroup(jDialog2Layout.createParallelGroup(jav
ax.swing.GroupLayout.Alignment.BASELINE)
288                     .addComponent(jButton8)
289                     .addComponent(jButton5))
290                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
_SIZE, Short.MAX_VALUE))
291         );
292
293         jLabel5.setText("jLabel5");
294
295         jButton3.setText("OK");
296         jButton3.addActionListener(new java.awt.event.ActionList
ener() {
297             public void actionPerformed(java.awt.event.ActionEve
nt evt) {
298                 jButton3ActionPerformed(evt);
299             }
300         });
301
302         javax.swing.GroupLayout jDialog3Layout = new javax.swing
.GroupLayout(jDialog3.getContentPane());
303         jDialog3.getContentPane().setLayout(jDialog3Layout);
304         jDialog3Layout.setHorizontalGroup(
305             jDialog3Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
306             .addGroup(javax.swing.GroupLayout.Alignment.TRAILING
```

```
, jDialog3Layout.createSequentialGroup()
307                 .addContainerGap(26, Short.MAX_VALUE)
308                 .addComponent(jLabel5, javax.swing.GroupLayout.P
REFERRED_SIZE, 279, javax.swing.GroupLayout.PREFERRED_SIZE)
309                 .addContainerGap())
310             .addGroup(jDialog3Layout.createSequentialGroup()
311                 .addGap(75, 75, 75)
312                 .addComponent(jButton3)
313                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
_SIZE, Short.MAX_VALUE))
314         );
315         jDialog3Layout.setVerticalGroup(
316             jDialog3Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
317             .addGroup(jDialog3Layout.createSequentialGroup()
318                 .addContainerGap(16, Short.MAX_VALUE)
319                 .addComponent(jLabel5)
320                 .addGap(18, 18, 18)
321                 .addComponent(jButton3)
322                 .addContainerGap())
323         );
324 
325         setDefaultCloseOperation(javax.swing.WindowConstants.EXI
T_ON_CLOSE);
326         setTitle("HMM Filter Implementation");
327         setCursor(new java.awt.Cursor(java.awt.Cursor.DEFAULT_CU
RSOR));
328         addMouseListener(new java.awt.event.MouseAdapter() {
329             public void mouseClicked(java.awt.event.MouseEvent e
vt) {
330                 formMouseClicked(evt);
331             }
332         });
333 //        getContentPane().setLayout(new org.netbeans.lib.awtext
ra.AbsoluteLayout());
334   //      getContentPane().add(jLabel2, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 60, 360, 20));
335     //    getContentPane().add(jLabel1, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 30, 370, 20));
336       //  getContentPane().add(jLabel3, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 90, 370, 20));
337         //getContentPane().add(jLabel4, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 120, 380, 20));
```

```
338
339             jMenu1.setText("File");
340             jMenu1.addMenuListener(new javax.swing.event.MenuListene
    r() {
341                 public void menuDeselected(javax.swing.event.MenuEve
    nt evt) {
342                     jMenu1MenuDeselected(evt);
343                 }
344                 public void menuCanceled(javax.swing.event.MenuEvent
    evt) {
345                 }
346                 public void menuSelected(javax.swing.event.MenuEvent
    evt) {
347                     jMenu1MenuSelected(evt);
348                 }
349             });
350
351             miOpen.setText("Open");
352             miOpen.addActionListener(new java.awt.event.ActionListen
    er() {
353                 public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
354                     miOpenActionPerformed(evt);
355                 }
356             });
357             jMenu1.add(miOpen);
358
359             miDeviation.setText("Calculate deviation");
360             miDeviation.addActionListener(new java.awt.event.ActionL
    istener() {
361                 public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
362                     miDeviationActionPerformed(evt);
363                 }
364             });
365             jMenu1.add(miDeviation);
366
367             miNoise.setText("Set Noise Parameters");
368             miNoise.addActionListener(new java.awt.event.ActionListe
    ner() {
369                 public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
370                     miNoiseActionPerformed(evt);
```

```
371             }
372         });
373         jMenu1.add(miNoise);
374 
375         HMMParameters.setText("Set Transition Probabilities");
376         HMMParameters.addActionListener(new java.awt.event.Actio
    nListener() {
377             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
378                 HMMParametersActionPerformed(evt);
379             }
380         });
381         jMenu1.add(HMMParameters);
382 
383         miClose.setAccelerator(javax.swing.KeyStroke.getKeyStrok
    e(java.awt.event.KeyEvent.VK_F4, java.awt.event.InputEvent.ALT_M
    ASK));
384         miClose.setText("Close");
385         miClose.addActionListener(new java.awt.event.ActionListe
    ner() {
386             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
387                 miCloseActionPerformed(evt);
388             }
389         });
390         jMenu1.add(miClose);
391 
392         jMenuBar1.add(jMenu1);
393 
394         setJMenuBar(jMenuBar1);
395 
396         pack();
397     }// </editor-fold>//GEN-END:initComponents
398 
399     private void miCloseActionPerformed(java.awt.event.ActionEve
    nt evt) {//GEN-FIRST:event_miCloseActionPerformed
400         System.exit(0);
401 
402     }//GEN-LAST:event_miCloseActionPerformed
403 
404     public static double calcDist(double p1, double p2) {
405         return Math.sqrt(Math.pow(p1-p2,2));
406     }
```

```
407
408
409
410
411     private void miDeviationActionPerformed(java.awt.event.Actio
    nEvent evt) {//GEN-FIRST:event_miDeviationActionPerformed
412         // υπολόγισε την απόκλιση του θορύβου, HMM filter από τη
    ν πραγματική τιμή
413         double deviationFromNoise = 0.0, deviationFromHMM = 0.0;

414         int num = num_measurements;
415
416         for (int i = 0; i < num; i++) {
417             deviationFromNoise += calcDist(real_measurements[i],
    noise_measurements[i]);
418             deviationFromHMM += calcDist( real_measurements[i],
    HMM_measurements[i]);
419         }
420
421         String message = "Deviation between noise and real measu
    rements: " + deviationFromNoise / num + "\n";
422         message += "Deviation between HMM filter results and rea
    l measurements: " + deviationFromHMM / num + "\n";
423         JOptionPane.showMessageDialog(null, message, "Calculated
    deviation values", JOptionPane.INFORMATION_MESSAGE);
424     }//GEN-LAST:event_miDeviationActionPerformed
425
426
427
428
429
430
431     private void miOpenActionPerformed(java.awt.event.ActionEven
    t evt) {//GEN-FIRST:event_miOpenActionPerformed
432         // Dialog box to open measurements file
433         int returnVal = fileChooser.showOpenDialog(this);
434         int i=0;
435         String display_real_measurements, display_noise_measurem
    ents, temp;
436         display_real_measurements=new String("measurements:    "
    );
437         display_noise_measurements=new String("measurements:  ")
    ;
```

```
438          temp=new String();
439
440
441          if (returnVal == JFileChooser.APPROVE_OPTION) {
442
443              // Clear screen
444              screen.setColor(Color.white);
445              screen.fillRect(0, 0, width, height);
446              screen.setColor(Color.black);
447              repaint();
448
449              File file = fileChooser.getSelectedFile();
450              try {
451                  FileReader fr = new FileReader(file.getAbsoluteP
    ath());
452                  LineNumberReader lnreader = new LineNumberReader
    (fr);
453                  String line=new String();
454                  String[] result;
455
456                  double x, noiseX;
457                  while ((line = lnreader.readLine()) != null) {
458                      result=line.split("\\s");
459
460                      real_measurements[i]= Integer.parseInt(resul
    t[0]);
461                      temp=String.valueOf(real_measurements[i]);
462                      display_real_measurements=display_real_measu
    rements+temp+" ";
463
464                      noise_measurements[i] = Integer.parseInt(res
    ult[1]);
465                      temp=String.valueOf(noise_measurements[i]);

466                      display_noise_measurements=display_noise_mea
    surements+temp+" ";
467
468                      i++;
469                  }
470                  num_measurements=i;
471
472                  jLabel1.setText("Real   ".concat(display_real_me
    asurements));
```

```
473                 jLabel2.setText("Noise   ".concat(display_noise_
    measurements));
474
475                 toggleHMMs();
476             } catch (IOException ex) {
477                 System.out.println("problem accessing file" + fi
    le.getAbsolutePath());
478             }
479         } else {
480             System.out.println("File access cancelled by user.")
    ;
481         }
482         miNoise.setEnabled(true);
483     }//GEN-LAST:event_miOpenActionPerformed
484
485 private void HMMParametersActionPerformed(java.awt.event.ActionE
    vent evt) {//GEN-FIRST:event_HMMParametersActionPerformed
486 jDialog1.setVisible(rootPaneCheckingEnabled);// TODO add your ha
    ndling code here:
487 jDialog1.setSize(487, 250);
488 jDialog1.setTitle("Transition probabilities");
489 }//GEN-LAST:event_HMMParametersActionPerformed
490
491 private void fileChooserActionPerformed(java.awt.event.ActionEve
    nt evt) {//GEN-FIRST:event_fileChooserActionPerformed
492 // TODO add your handling code here:
493 }//GEN-LAST:event_fileChooserActionPerformed
494
495 private void jMenu1MenuDeselected(javax.swing.event.MenuEvent ev
    t) {//GEN-FIRST:event_jMenu1MenuDeselected
496 // TODO add your handling code here:
497     repaint();
498 }//GEN-LAST:event_jMenu1MenuDeselected
499
500     private void formMouseClicked(java.awt.event.MouseEvent evt)
    {//GEN-FIRST:event_formMouseClicked
501         // TODO add your handling code here:
502     }//GEN-LAST:event_formMouseClicked
503
504     private void jButton4ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton4ActionPerformed
505         // TODO add your handling code here:
506         jDialog1.dispose();
```

```
507       }//GEN-LAST:event_jButton4ActionPerformed
508
509
510
511       private void jButton1ActionPerformed(java.awt.event.ActionEv
      ent evt) {//GEN-FIRST:event_jButton1ActionPerformed
512           //Read transition probabilities
513           int x, y;
514           String temp;
515           for(x=0;x<num_states;x++)
516               for(y=1;y<=num_states;y++)
517               {
518                   temp=(jTable1.getValueAt(x,y)).toString();

519                   transition_probabilities[x][y-
      1]=Double.valueOf(temp).doubleValue();
520               }
521           jDialog1.dispose();
522       }//GEN-LAST:event_jButton1ActionPerformed
523
524
525
526       private void jButton5ActionPerformed(java.awt.event.ActionEv
      ent evt) {//GEN-FIRST:event_jButton5ActionPerformed
527           // Read noise probabilities
528           int x, y;
529           String temp;
530           for(x=0;x<num_states;x++)
531               for(y=1;y<=num_states;y++)
532               {
533                   temp=(jTable2.getValueAt(x,y)).toString();

534                   noise_probabilities[x][y-
      1]=Double.valueOf(temp).doubleValue();
535               }
536           calculate_state_probabilities();
537           jDialog2.dispose();
538
539
540       }//GEN-LAST:event_jButton5ActionPerformed
541
542       private void jButton8ActionPerformed(java.awt.event.ActionEv
      ent evt) {//GEN-FIRST:event_jButton8ActionPerformed
```

```
543          // TODO add your handling code here:
544          jDialog2.dispose();
545      }//GEN-LAST:event_jButton8ActionPerformed
546
547      private void miNoiseActionPerformed(java.awt.event.ActionEve
     nt evt) {//GEN-FIRST:event_miNoiseActionPerformed
548          // TODO add your handling code here:
549      jDialog2.setVisible(rootPaneCheckingEnabled);
550      jDialog2.setSize(487, 250);
551      jDialog2.setTitle("Set Noise Parameters");
552      }//GEN-LAST:event_miNoiseActionPerformed
553
554      private void jButton2ActionPerformed(java.awt.event.ActionEv
     ent evt) {//GEN-FIRST:event_jButton2ActionPerformed
555          // Check box to enable exhaustive search decoding or Vit
     erbi decoding
556
557          jButton1ActionPerformed(evt);
558
559          if(jCheckBox1.isSelected()==true)
560          {
561              calculateHMM_Viterbi();
562          }
563          else
564          {
565              calculateHMM();
566          }
567
568      }//GEN-LAST:event_jButton2ActionPerformed
569
570      private void jMenu1MenuSelected(javax.swing.event.MenuEvent
     evt) {//GEN-FIRST:event_jMenu1MenuSelected
571          // TODO add your handling code here:
572          if(file_opened==0)
573          {
574              miNoise.setEnabled(false);
575              HMMParameters.setEnabled(false);
576          }
577          file_opened=1;
578      }//GEN-LAST:event_jMenu1MenuSelected
579
580      private void jButton3ActionPerformed(java.awt.event.ActionEv
     ent evt) {//GEN-FIRST:event_jButton3ActionPerformed
```

```
581           // TODO add your handling code here:
582           jDialog3.dispose();
583       }//GEN-LAST:event_jButton3ActionPerformed
584   
585   
586   
587       void calculate_state_probabilities()
588       {
589           //Set HMM state probabilities
590           int x, y;
591           double temp=0;
592   
593           for(y=0;y<num_measurements;y++)
594           {
595               for(x=0;x<num_states;x++)
596               {
597                   state_probabilities[x][y]=noise_probabilities[no
      ise_measurements[y]][x];
598   //                System.out.println(noise_measurements[y]);
599   //                System.out.println(Arrays.deepToString(state_p
      robabilities));
600               }
601           }
602           HMMParameters.setEnabled(true);
603   
604       }
605   
606   
607   
608       void toggleHMMs() {
609           // Can be used to hide or show the HMM filter series. Cu
      rrently unused
610           if(toggled==0)
611           {
612               jLabel3.setText("Filtered measurements: ");
613               jLabel4.setText("Filtered measurements (Viterbi):  "
      );
614               toggled=1;
615           }
616               else
617               {
618                   toggled=0;
619                   jLabel3.setText(null);
```

```
620                 jLabel4.setText(null);
621             }
622     }
623
624
625
626     void calculateHMM_Viterbi()
627     {
628         // Viterbi decoding
629         int counter1, counter2, counter3;
630         double tmp[][], temp=0.0, max_value=0.0, temp1, temp2, t
    emp3;
631         int output_path[], current_path[];
632
633         output_path=new int[num_measurements]; //The
634         current_path=new int[num_measurements];
635         tmp=new double[num_states][num_measurements];
636
637         String path=new String();
638         long start = System.nanoTime();
639
640         for(counter1=0;counter1<num_measurements;counter1++) //I
    nitializations
641         {
642            output_path[counter1]=-1;
643            current_path[counter1]=-1;
644            for(counter2=0;counter2<num_states;counter2++)
645            {
646                 best_path[counter2][counter1]=-1;
647                 tmp[counter2][counter1]=state_probabilities[coun
    ter2][counter1];
648            }
649         }
650
651
652
653         for(counter1=1;counter1<num_measurements;counter1++) //I
    dentify the best path to each state for each measurement
654         {
655             for(counter2=0;counter2<num_states;counter2++)
656             {
657                 max_value=0.0;
658                 for(counter3=0;counter3<num_states;counter3++)
```

```
659                 {
660                     temp=tmp[counter3][counter1-
    1]*transition_probabilities[counter3][counter2];
661
662                     if(temp>max_value)
663                     {
664                         max_value=temp;
665                         best_path[counter2][counter1]=counter3;
    //Memorize the previous node for the best path to the current on
    e
666                     }
667                 }
668                 tmp[counter2][counter1]*=max_value;
669             }
670         }
671
672
673
674         max_value=0;
675         temp=-1;
676
677         for(counter2=0;counter2<num_states;counter2++) //Find the
    best path for the st of paths to each state of the final measure
    ment
678         {
679             counter1=num_measurements-1;
680             current_path[counter1]=counter2;
681             temp3=state_probabilities[counter2][counter1];
682
683             while((best_path[current_path[counter1]][counter1]>-
    1)&&(counter1>0))
684             {
685                 temp1=state_probabilities[best_path[current_path[
    counter1]][counter1]][counter1-1];
686                 temp2=transition_probabilities[best_path[current_
    path[counter1]][counter1]][current_path[counter1]];
687                 temp=temp1*temp2*temp3;
688                 current_path[counter1-
```

```
1]=best_path[current_path[counter1]][counter1];
689                 counter1--
;

690             }
691
692            if((temp>max_value)&&(counter1==0))
693             {
694                 max_value=temp;
695                 for(counter3=0;counter3<num_measurements;counter3
++)
696                 {
697                     output_path[counter3]=current_path[counter3];

698                     HMM_measurements[counter3]=output_path[counte
r3];
699                 }
700             }
701         }
702
703
704         for(counter1=0;counter1<num_measurements;counter1++)
705         {
706             path=path+String.valueOf(output_path[counter1]);
707             path=path+" ";
708         }
709
710          jLabel4.setText("Filtered measurements (Viterbi): "+ pat
h);
711
712          double elapsedTime = System.nanoTime()-start;
713          elapsedTime/=Math.pow(10,6);
714
715          jDialog3.setVisible(rootPaneCheckingEnabled);
716          jDialog3.setSize(200, 120);
717          jDialog3.setTitle("Viterbi decoder");
718          jLabel5.setText("Running time: "+String.valueOf(elapsedT
ime)+" msec");
719          System.out.println(elapsedTime);
720     }
721
722
723
```

```
724
725
726
727
728
729     void calculateHMM() {
730         //Exhaustive search decoding
731         long counter, num_paths;
732
733         double max_value=0, temp=1.0, temp1, temp2;
734         int output_path[], current_path[],counter1;
735         boolean updated;
736         String path=new String();
737         output_path= new int[num_measurements];
738         current_path= new int[num_measurements];
739
740         long start = System.nanoTime();
741
742         num_paths=(long) Math.pow(num_states, num_measurements);
    //The number of all paths to exhaustively search
743
744         for(counter1=0;counter1<num_measurements;counter1++)
745         {
746             current_path[counter1]=0;
747         }
748
749         for(counter=0;counter<num_paths;counter++) //Search each
    path and find the best one
750         {
751             for(counter1=0;counter1<num_measurements;counter1++)

752             {
753                 if(counter1<num_measurements-1)
754                 {
755                     temp1=state_probabilities[current_path[count
    er1]][counter1];
756                     temp2=transition_probabilities[current_path[
    counter1]][current_path[counter1+1]];
757
758                     temp*=temp1*temp2;
759                 }
760                 else
761                 {
```

```
762                     temp1=state_probabilities[current_path[count
    er1]][counter1];
763                     temp*=temp1;
764                 }
765             }
766 
767 
768             if(temp>=max_value) //If true, this path is currentl
    y the best path
769             {
770                 max_value=temp;
771                 for(counter1=0;counter1<num_measurements;counter
    1++)
772                 {
773                    output_path[counter1]=current_path[counter1];

774                    HMM_measurements[counter1]=current_path[count
    er1];
775                 }
776              }
777 
778             temp=1.0;
779             counter1=num_measurements-1;
780 
781             while(current_path[counter1]+1>=num_states) //calcul
    ate the next path to check
782             {
783                 current_path[counter1]=0;
784                 counter1--;
785                 if(counter1<0)
786                     break;
787             }
788 
789             if(counter1>=0)
790                 current_path[counter1]++;

791         }
792 
793 
794          for(counter1=0;counter1<num_measurements;counter1++)
795          {
796             path=path+String.valueOf(output_path[counter1]);
797             path=path+" ";
```

```
798             }
799 
800 
801             jLabel3.setText("Filtered measurements:"+ path);
802 
803             double elapsedTime = System.nanoTime()-start;
804             elapsedTime/=Math.pow(10,6);
805 
806             jDialog3.setVisible(rootPaneCheckingEnabled);
807             jDialog3.setSize(230, 120);
808             jDialog3.setTitle("Exhaustive search decoder");
809             jLabel5.setText("Running time: "+String.valueOf(elapsedT
    ime)+" msec");
810             System.out.println(elapsedTime);
811 
812         }
813 
814 
815 
816         @Override
817         public void update(Graphics g) {
818             //g.drawImage(backbuffer, 0, menubar_height, this);
819         }
820 
821         @Override
822         public void paint(Graphics g) {
823             super.paint(g);
824             //update(g);
825         }
826 
827 
828         /**
829         * @param args the command line arguments
830         */
831         public static void main(String args[]) {
832             java.awt.EventQueue.invokeLater(new Runnable() {
833                 public void run() {
834                     new HMMFilter().setVisible(true);
835                 }
836             });
837     }
838 
839         // Variables declaration - do not modify//GEN-
```

```
    BEGIN:variables
840     private javax.swing.JMenuItem HMMParameters;
841     private javax.swing.JFileChooser fileChooser;
842     private javax.swing.JButton jButton1;
843     private javax.swing.JButton jButton2;
844     private javax.swing.JButton jButton3;
845     private javax.swing.JButton jButton4;
846     private javax.swing.JButton jButton5;
847     private javax.swing.JButton jButton8;
848     private javax.swing.JCheckBox jCheckBox1;
849     private javax.swing.JDialog jDialog1;
850     private javax.swing.JDialog jDialog2;
851     private javax.swing.JDialog jDialog3;
852     private javax.swing.JFileChooser jFileChooser1;
853     private javax.swing.JInternalFrame jInternalFrame1;
854     private javax.swing.JLabel jLabel1;
855     private javax.swing.JLabel jLabel2;
856     private javax.swing.JLabel jLabel3;
857     private javax.swing.JLabel jLabel4;
858     private javax.swing.JLabel jLabel5;
859     private javax.swing.JMenu jMenu1;
860     private javax.swing.JMenuBar jMenuBar1;
861     private javax.swing.JPanel jPanel1;
862     private javax.swing.JScrollPane jScrollPane1;
863     private javax.swing.JScrollPane jScrollPane2;
864     private javax.swing.JTable jTable1;
865     private javax.swing.JTable jTable2;
866     private javax.swing.JMenuItem miClose;
867     private javax.swing.JMenuItem miDeviation;
868     private javax.swing.JMenuItem miNoise;
869     private javax.swing.JMenuItem miOpen;
870     // End of variables declaration//GEN-END:variables
871
}
```

Java Code for HMM filter with map-aware Transition Probability Table:

```
1  package ModMarkov;
2
3 import java.awt.Color;
4 import java.awt.Graphics;
5 import java.awt.Image;
6 import java.io.File;
7 import java.io.FileReader;
8 import java.io.IOException;
9 import java.io.LineNumberReader;
10    import java.util.StringTokenizer;
11
12    import javax.swing.JFileChooser;
13    import javax.swing.JMenuBar;
14    import javax.swing.JOptionPane;
15
16    @SuppressWarnings("serial")
17    public class HMMFilter extends javax.swing.JFrame {
18
19        int num_states = 9; //The number of possible states
20        final int menubar_height = 50;
21        int num_measurements = 0;  // how many measurements I have s
      tored so far
22        int[] real_measurements;   // the actual mesurements
23        int[] noise_measurements;   // the 'noise' measurements
24        int[] HMM_measurements;     // the calculated filter values

25        int[][] best_path; //shows the previous neighbour in the bes
      t HMM path
26        double[][] transition_probabilities; //HMM model transition
      probability
27        double[][] state_probabilities; //HMM model state probabilit
      y
28        double[][] noise_probabilities; // Input noise data structur
      e
29        double max_value;
30        int file_opened=0;
31        int width, height;
32        int toggled=0;
33        Image backbuffer;
34        Graphics screen;
```

```
35
36      /** Creates new form HMMFilter */
37      public HMMFilter() {
38          initComponents();
39
40          real_measurements = new int[4];   // αρχικοποιήσεις
41          noise_measurements = new int[4];
42          HMM_measurements = new int[4];
43          best_path=new int[num_states][4];
44          transition_probabilities=new double[num_states][num_stat
    es];
45          state_probabilities=new double[num_states][4];
46          noise_probabilities=new double[num_states][num_states];

47
48          setSize(500,400);
49          width= getSize().width;
50          height=getSize().height;
51
52          backbuffer = createImage(width, height);
53          screen = backbuffer.getGraphics();
54          screen.setColor(Color.white);
55          screen.fillRect(0, 0, width, height);
56          screen.setColor(Color.black);
57
58
59      }
60
61      /** This method is called from within the constructor to
62       * initialize the form.
63       * WARNING: Do NOT modify this code. The content of this met
    hod is
64       * always regenerated by the Form Editor.
65       */
66      @SuppressWarnings("unchecked")
67      // <editor-
    fold defaultstate="collapsed" desc="Generated Code">//GEN-
    BEGIN:initComponents
68      private void initComponents() {
69
70          jDialog1 = new javax.swing.JDialog();
71          jButton1 = new javax.swing.JButton();
72          jButton4 = new javax.swing.JButton();
```

```
73            jScrollPane1 = new javax.swing.JScrollPane();
74            jTable1 = new javax.swing.JTable();
75            jButton2 = new javax.swing.JButton();
76            jCheckBox1 = new javax.swing.JCheckBox();
77            jFileChooser1 = new javax.swing.JFileChooser();
78            jPanel1 = new javax.swing.JPanel();
79            jInternalFrame1 = new javax.swing.JInternalFrame();
80            fileChooser = new javax.swing.JFileChooser();
81            jDialog2 = new javax.swing.JDialog();
82            jButton5 = new javax.swing.JButton();
83            jButton8 = new javax.swing.JButton();
84            jScrollPane2 = new javax.swing.JScrollPane();
85            jTable2 = new javax.swing.JTable();
86            jDialog3 = new javax.swing.JDialog();
87            jLabel5 = new javax.swing.JLabel();
88            jButton3 = new javax.swing.JButton();
89            jLabel2 = new javax.swing.JLabel();
90            jLabel1 = new javax.swing.JLabel();
91            jLabel3 = new javax.swing.JLabel();
92            jLabel4 = new javax.swing.JLabel();
93            jMenuBar1 = new javax.swing.JMenuBar();
94            jMenu1 = new javax.swing.JMenu();
95            miOpen = new javax.swing.JMenuItem();
96            miDeviation = new javax.swing.JMenuItem();
97            miNoise = new javax.swing.JMenuItem();
98            HMMParameters = new javax.swing.JMenuItem();
99            miClose = new javax.swing.JMenuItem();
100
101           jButton1.setText("OK&Close");
102           jButton1.addActionListener(new java.awt.event.ActionList
      ener() {
103               public void actionPerformed(java.awt.event.ActionEve
      nt evt) {
104                   jButton1ActionPerformed(evt);
105               }
106           });
107
108           jButton4.setText("Close");
109           jButton4.addActionListener(new java.awt.event.ActionList
      ener() {
110               public void actionPerformed(java.awt.event.ActionEve
      nt evt) {
111                   jButton4ActionPerformed(evt);
```

```
112                 }
113             });
114 
115             jTable1.setModel(new javax.swing.table.DefaultTableModel
    ( //transition probability table
116                 new Object [][] {
117                         {"1",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.0), new Float(0.0),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)},
118                         {"2",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.0), new Float(0.0),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)},
119                         {"3",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.0), new Float(0.0),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)},
120                         {"4",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.2),  new Float(0.4), new Float(0.0),  n
    ew Float(0.4),  new Float(0.0),  new Float(0.0)},
121                         {"5",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.4),  new Float(0.1), new Float(0.4),  n
    ew Float(0.1),  new Float(0.0),  new Float(0.0)},
122                         {"6",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.7), new Float(0.3),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)},
123                         {"7",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.7),  new Float(0.1), new Float(0.0),  n
    ew Float(0.2),  new Float(0.0),  new Float(0.0)},
124                         {"8",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.0), new Float(0.0),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)},
125                         {"9",  new Float(0.0),  new Float(0.0),  new
    Float(0.0),  new Float(0.0),  new Float(0.0), new Float(0.0),  n
    ew Float(0.0),  new Float(0.0),  new Float(0.0)}
126                 },
127 
128 
129                 new String [] {
130                         "    Pij", "      0","     1", "     2", "
    3", "     4", "     5", "     6", "     7", "     8"
131                 }
132             ) {
133                 Class[] types = new Class [] {
134                         java.lang.String.class, java.lang.Float.clas
```

```
s, java.lang.Float.class, java.lang.Float.class, java.lang.Float
.class, java.lang.Float.class, java.lang.Float.class, java.lang.
Float.class, java.lang.Float.class, java.lang.Float.class
                    };

            public Class getColumnClass(int columnIndex) {
                return types [columnIndex];
            }
        });
        jScrollPane1.setViewportView(jTable1);
        jTable1.getColumnModel().getColumn(0).setResizable(true)
;

        jButton2.setText("OK&Filter");
        jButton2.addActionListener(new java.awt.event.ActionList
ener() {
            public void actionPerformed(java.awt.event.ActionEve
nt evt) {
                jButton2ActionPerformed(evt);
            }
        });

        jCheckBox1.setText("Use Viterbi decoding");

        javax.swing.GroupLayout jDialog1Layout = new javax.swing
.GroupLayout(jDialog1.getContentPane());
        jDialog1.getContentPane().setLayout(jDialog1Layout);
        jDialog1Layout.setHorizontalGroup(
            jDialog1Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
            .addGroup(jDialog1Layout.createSequentialGroup()
                .addContainerGap()
                .addGroup(jDialog1Layout.createParallelGroup(jav
ax.swing.GroupLayout.Alignment.LEADING)
                    .addComponent(jScrollPane1, javax.swing.Grou
pLayout.Alignment.TRAILING)
                    .addGroup(jDialog1Layout.createSequentialGro
up()
                        .addComponent(jButton1)
                        .addGap(106, 106, 106)
                        .addComponent(jButton2)
                        .addPreferredGap(javax.swing.LayoutStyle
.ComponentPlacement.RELATED, javax.swing.GroupLayout.DEFAULT_SIZ
```

```
E, Short.MAX_VALUE)
166                         .addComponent(jButton4)))
167                 .addContainerGap())
168             .addGroup(jDialog1Layout.createSequentialGroup()
169                 .addGap(173, 173, 173)
170                 .addComponent(jCheckBox1)
171                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
    _SIZE, Short.MAX_VALUE))
172         );
173         jDialog1Layout.setVerticalGroup(
174             jDialog1Layout.createParallelGroup(javax.swing.Group
    Layout.Alignment.LEADING)
175             .addGroup(jDialog1Layout.createSequentialGroup()
176                 .addContainerGap()
177                 .addComponent(jScrollPane1, javax.swing.GroupLay
    out.PREFERRED_SIZE, 109, javax.swing.GroupLayout.PREFERRED_SIZE)

178                 .addGap(18, 18, 18)
179                 .addComponent(jCheckBox1)
180                 .addPreferredGap(javax.swing.LayoutStyle.Compone
    ntPlacement.UNRELATED)
181                 .addGroup(jDialog1Layout.createParallelGroup(jav
    ax.swing.GroupLayout.Alignment.BASELINE)
182                     .addComponent(jButton4)
183                     .addComponent(jButton1)
184                     .addComponent(jButton2))
185                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
    _SIZE, Short.MAX_VALUE))
186         );
187
188         javax.swing.GroupLayout jPanel1Layout = new javax.swing.
    GroupLayout(jPanel1);
189         jPanel1.setLayout(jPanel1Layout);
190         jPanel1Layout.setHorizontalGroup(
191             jPanel1Layout.createParallelGroup(javax.swing.GroupL
    ayout.Alignment.LEADING)
192             .addGap(0, 100, Short.MAX_VALUE)
193         );
194         jPanel1Layout.setVerticalGroup(
195             jPanel1Layout.createParallelGroup(javax.swing.GroupL
    ayout.Alignment.LEADING)
196             .addGap(0, 100, Short.MAX_VALUE)
197         );
```

```
198
199         jInternalFrame1.setVisible(true);
200
201         fileChooser.addActionListener(new java.awt.event.ActionL
    istener() {
202             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
203                 fileChooserActionPerformed(evt);
204             }
205         });
206
207         javax.swing.GroupLayout jInternalFrame1Layout = new java
    x.swing.GroupLayout(jInternalFrame1.getContentPane());
208         jInternalFrame1.getContentPane().setLayout(jInternalFram
    e1Layout);
209         jInternalFrame1Layout.setHorizontalGroup(
210             jInternalFrame1Layout.createParallelGroup(javax.swin
    g.GroupLayout.Alignment.LEADING)
211             .addGroup(jInternalFrame1Layout.createSequentialGrou
    p()
212                 .addContainerGap()
213                 .addComponent(fileChooser, javax.swing.GroupLayo
    ut.PREFERRED_SIZE, javax.swing.GroupLayout.DEFAULT_SIZE, javax.s
    wing.GroupLayout.PREFERRED_SIZE)
214                 .addContainerGap())
215         );
216         jInternalFrame1Layout.setVerticalGroup(
217             jInternalFrame1Layout.createParallelGroup(javax.swin
    g.GroupLayout.Alignment.LEADING)
218             .addGroup(jInternalFrame1Layout.createSequentialGrou
    p()
219                 .addContainerGap()
220                 .addComponent(fileChooser, javax.swing.GroupLayo
    ut.PREFERRED_SIZE, 256, javax.swing.GroupLayout.PREFERRED_SIZE)

221                 .addContainerGap())
222         );
223
224         jButton5.setText("OK&Close");
225         jButton5.addActionListener(new java.awt.event.ActionList
    ener() {
226             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
```

```
227                 jButton5ActionPerformed(evt);
228             }
229         });
230 
231         jButton8.setText("Close");
232         jButton8.addActionListener(new java.awt.event.ActionListener() {
233             public void actionPerformed(java.awt.event.ActionEvent evt) {
234                 jButton8ActionPerformed(evt);
235             }
236         });
237 
238         jTable2.setModel(new javax.swing.table.DefaultTableModel(   //noise probability table
239             new Object [][] {
240                     {"1", new Float(0.05), new Float(0.3), new Float(0.01), new Float(0.3), new Float(0.3), new Float(0.01), new Float(0.01), new Float(0.01)},
241                     {"2", new Float(0.15), new Float(0.12), new Float(0.15), new Float(0.15), new Float(0.15), new Float(0.15), new Float(0.01), new Float(0.01), new Float(0.01)},
242                     {"3", new Float(0.01), new Float(0.25), new Float(0.05), new Float(0.01), new Float(0.01), new Float(0.4), new Float(0.01), new Float(0.01), new Float(0.01)},
243                     {"4", new Float(0.2), new Float(0.1), new Float(0.01), new Float(0.07), new Float(0.07), new Float(0.01), new Float(0.2), new Float(0.1), new Float(0.01)},
244                     {"5", new Float(0.1), new Float(0.1), new Float(0.1), new Float(0.1), new Float(0.1), new Float(0.2), new Float(0.1), new Float(0.1), new Float(0.1)},
245                     {"6", new Float(0.01), new Float(0.1), new Float(0.2), new Float(0.01), new Float(0.01), new Float(0.07), new Float(0.01), new Float(0.1), new Float(0.2)},
246                     {"7", new Float(0.01), new Float(0.01), new Float(0.01), new Float(0.4), new Float(0.4), new Float(0.01), new Float(0.05), new Float(0.2), new Float(0.01)},
247                     {"8", new Float(0.01), new Float(0.01), new Float(0.01), new Float(0.15), new Float(0.15), new Float(0.15), new Float(0.15), new Float(0.12), new Float(0.15)},
248                     {"9", new Float(0.01), new Float(0.01), new Float(0.01), new Float(0.01), new Float(0.01), new Float(0.4), new Float(0.01), new Float(0.25), new Float(0.05)}
```

```
249             },
250             new String [] {
251                 "    Pij", "      0","     1", "     2", "     3
    ", "     4", "     5", "     6", "     7", "     8"
252             }
253         ) {
254             Class[] types = new Class [] {
255                     java.lang.String.class, java.lang.Float.clas
    s, java.lang.Float.class, java.lang.Float.class, java.lang.Float
    .class, java.lang.Float.class, java.lang.Float.class, java.lang.
    Float.class, java.lang.Float.class, java.lang.Float.class
256                     };
257 
258             public Class getColumnClass(int columnIndex) {
259                 return types [columnIndex];
260             }
261         });
262         jScrollPane2.setViewportView(jTable2);
263         jTable2.getColumnModel().getColumn(0).setResizable(true)
    ;
264 
265         javax.swing.GroupLayout jDialog2Layout = new javax.swing
    .GroupLayout(jDialog2.getContentPane());
266         jDialog2.getContentPane().setLayout(jDialog2Layout);
267         jDialog2Layout.setHorizontalGroup(
268             jDialog2Layout.createParallelGroup(javax.swing.Group
    Layout.Alignment.LEADING)
269             .addGroup(jDialog2Layout.createSequentialGroup()
270                 .addContainerGap()
271                 .addGroup(jDialog2Layout.createParallelGroup(jav
    ax.swing.GroupLayout.Alignment.LEADING)
272                     .addComponent(jScrollPane2, javax.swing.Grou
    pLayout.Alignment.TRAILING)
273                     .addGroup(jDialog2Layout.createSequentialGro
    up()
274                         .addComponent(jButton5)
275                         .addPreferredGap(javax.swing.LayoutStyle
    .ComponentPlacement.RELATED, javax.swing.GroupLayout.DEFAULT_SIZ
    E, Short.MAX_VALUE)
276                         .addComponent(jButton8)))
277                 .addContainerGap())
278         );
279         jDialog2Layout.setVerticalGroup(
```

```
280             jDialog2Layout.createParallelGroup(javax.swing.Group
    Layout.Alignment.LEADING)
281             .addGroup(jDialog2Layout.createSequentialGroup()
282                 .addContainerGap()
283                 .addComponent(jScrollPane2, javax.swing.GroupLay
    out.PREFERRED_SIZE, 109, javax.swing.GroupLayout.PREFERRED_SIZE)

284                 .addGap(48, 48, 48)
285                 .addGroup(jDialog2Layout.createParallelGroup(jav
    ax.swing.GroupLayout.Alignment.BASELINE)
286                     .addComponent(jButton8)
287                     .addComponent(jButton5))
288                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
    _SIZE, Short.MAX_VALUE))
289         );
290 
291         jLabel5.setText("jLabel5");
292 
293         jButton3.setText("OK");
294         jButton3.addActionListener(new java.awt.event.ActionList
    ener() {
295             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
296                 jButton3ActionPerformed(evt);
297             }
298         });
299 
300         javax.swing.GroupLayout jDialog3Layout = new javax.swing
    .GroupLayout(jDialog3.getContentPane());
301         jDialog3.getContentPane().setLayout(jDialog3Layout);
302         jDialog3Layout.setHorizontalGroup(
303             jDialog3Layout.createParallelGroup(javax.swing.Group
    Layout.Alignment.LEADING)
304             .addGroup(javax.swing.GroupLayout.Alignment.TRAILING
    , jDialog3Layout.createSequentialGroup()
305                 .addContainerGap(26, Short.MAX_VALUE)
306                 .addComponent(jLabel5, javax.swing.GroupLayout.P
    REFERRED_SIZE, 279, javax.swing.GroupLayout.PREFERRED_SIZE)
307                 .addContainerGap())
308             .addGroup(jDialog3Layout.createSequentialGroup()
309                 .addGap(75, 75, 75)
310                 .addComponent(jButton3)
311                 .addContainerGap(javax.swing.GroupLayout.DEFAULT
```

```
_SIZE, Short.MAX_VALUE))
312         );
313         jDialog3Layout.setVerticalGroup(
314             jDialog3Layout.createParallelGroup(javax.swing.Group
Layout.Alignment.LEADING)
315             .addGroup(jDialog3Layout.createSequentialGroup()
316                 .addContainerGap(16, Short.MAX_VALUE)
317                 .addComponent(jLabel5)
318                 .addGap(18, 18, 18)
319                 .addComponent(jButton3)
320                 .addContainerGap())
321         );
322 
323         setDefaultCloseOperation(javax.swing.WindowConstants.EXI
T_ON_CLOSE);
324         setTitle("HMM Filter Implementation");
325         setCursor(new java.awt.Cursor(java.awt.Cursor.DEFAULT_CU
RSOR));
326         addMouseListener(new java.awt.event.MouseAdapter() {
327             public void mouseClicked(java.awt.event.MouseEvent e
vt) {
328                 formMouseClicked(evt);
329             }
330         });
331 //        getContentPane().setLayout(new org.netbeans.lib.awtext
ra.AbsoluteLayout());
332   //      getContentPane().add(jLabel2, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 60, 360, 20));
333     //    getContentPane().add(jLabel1, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 30, 370, 20));
334       //  getContentPane().add(jLabel3, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 90, 370, 20));
335         //getContentPane().add(jLabel4, new org.netbeans.lib.awt
extra.AbsoluteConstraints(20, 120, 380, 20));
336 
337         jMenu1.setText("File");
338         jMenu1.addMenuListener(new javax.swing.event.MenuListene
r() {
339             public void menuDeselected(javax.swing.event.MenuEve
nt evt) {
340                 jMenu1MenuDeselected(evt);
341             }
342             public void menuCanceled(javax.swing.event.MenuEvent
```

```
evt) {
343             }
344             public void menuSelected(javax.swing.event.MenuEvent
evt) {
345                 jMenu1MenuSelected(evt);
346             }
347         });
348 
349         miOpen.setText("Open");
350         miOpen.addActionListener(new java.awt.event.ActionListen
er() {
351             public void actionPerformed(java.awt.event.ActionEve
nt evt) {
352                 miOpenActionPerformed(evt);
353             }
354         });
355         jMenu1.add(miOpen);
356 
357         miDeviation.setText("Calculate deviation");
358         miDeviation.addActionListener(new java.awt.event.ActionL
istener() {
359             public void actionPerformed(java.awt.event.ActionEve
nt evt) {
360                 miDeviationActionPerformed(evt);
361             }
362         });
363         jMenu1.add(miDeviation);
364 
365         miNoise.setText("Set Noise Parameters");
366         miNoise.addActionListener(new java.awt.event.ActionListe
ner() {
367             public void actionPerformed(java.awt.event.ActionEve
nt evt) {
368                 miNoiseActionPerformed(evt);
369             }
370         });
371         jMenu1.add(miNoise);
372 
373         HMMParameters.setText("Set Transition Probabilities");
374         HMMParameters.addActionListener(new java.awt.event.Actio
nListener() {
375             public void actionPerformed(java.awt.event.ActionEve
nt evt) {
```

```
376                 HMMParametersActionPerformed(evt);
377             }
378         });
379         jMenu1.add(HMMParameters);
380 
381         miClose.setAccelerator(javax.swing.KeyStroke.getKeyStrok
    e(java.awt.event.KeyEvent.VK_F4, java.awt.event.InputEvent.ALT_M
    ASK));
382         miClose.setText("Close");
383         miClose.addActionListener(new java.awt.event.ActionListe
    ner() {
384             public void actionPerformed(java.awt.event.ActionEve
    nt evt) {
385                 miCloseActionPerformed(evt);
386             }
387         });
388         jMenu1.add(miClose);
389 
390         jMenuBar1.add(jMenu1);
391 
392         setJMenuBar(jMenuBar1);
393 
394         pack();
395     }// </editor-fold>//GEN-END:initComponents
396 
397     private void miCloseActionPerformed(java.awt.event.ActionEve
    nt evt) {//GEN-FIRST:event_miCloseActionPerformed
398         System.exit(0);
399 
400     }//GEN-LAST:event_miCloseActionPerformed
401 
402     public static double calcDist(double p1, double p2) {
403         return Math.sqrt(Math.pow(p1-p2,2));
404     }
405 
406 
407 
408 
409     private void miDeviationActionPerformed(java.awt.event.Actio
    nEvent evt) {//GEN-FIRST:event_miDeviationActionPerformed
410         // υπολόγισε την απόκλιση του θορύβου, HMM filter από τη
    ν πραγματική τιμή
411         double deviationFromNoise = 0.0, deviationFromHMM = 0.0;
```

```
412             int num = num_measurements;
413 
414             for (int i = 0; i < num; i++) {
415                 deviationFromNoise += calcDist(real_measurements[i],
    noise_measurements[i]);
416                 deviationFromHMM += calcDist( real_measurements[i],
    HMM_measurements[i]);
417             }
418 
419             String message = "Deviation between noise and real measu
    rements: " + deviationFromNoise / num + "\n";
420             message += "Deviation between HMM filter results and rea
    l measurements: " + deviationFromHMM / num + "\n";
421             JOptionPane.showMessageDialog(null, message, "Calculated
    deviation values", JOptionPane.INFORMATION_MESSAGE);
422         }//GEN-LAST:event_miDeviationActionPerformed
423 
424 
425 
426 
427 
428 
429         private void miOpenActionPerformed(java.awt.event.ActionEven
    t evt) {//GEN-FIRST:event_miOpenActionPerformed
430             // Dialog box to open measurements file
431             int returnVal = fileChooser.showOpenDialog(this);
432             int i=0;
433             String display_real_measurements, display_noise_measurem
    ents, temp;
434             display_real_measurements=new String("measurements:    "
    );
435             display_noise_measurements=new String("measurements:  ")
    ;
436             temp=new String();
437 
438 
439             if (returnVal == JFileChooser.APPROVE_OPTION) {
440 
441                 // Clear screen
442                 screen.setColor(Color.white);
443                 screen.fillRect(0, 0, width, height);
444                 screen.setColor(Color.black);
```

```
445             repaint();
446
447             File file = fileChooser.getSelectedFile();
448             try {
449                 FileReader fr = new FileReader(file.getAbsoluteP
    ath());
450                 LineNumberReader lnreader = new LineNumberReader
    (fr);
451                 String line=new String();
452                 String[] result;
453
454                 double x, noiseX;
455                 while ((line = lnreader.readLine()) != null) {
456                     result=line.split("\\s");
457
458                     real_measurements[i]= Integer.parseInt(resul
    t[0]);
459                     temp=String.valueOf(real_measurements[i]);
460                     display_real_measurements=display_real_measu
    rements+temp+" ";
461
462                     noise_measurements[i] = Integer.parseInt(res
    ult[1]);
463                     temp=String.valueOf(noise_measurements[i]);

464                     display_noise_measurements=display_noise_mea
    surements+temp+" ";
465
466                     i++;
467                 }
468                 num_measurements=i;
469
470                 jLabel1.setText("Real   ".concat(display_real_me
    asurements));
471                 jLabel2.setText("Noise   ".concat(display_noise_
    measurements));
472
473                 toggleHMMs();
474             } catch (IOException ex) {
475                 System.out.println("problem accessing file" + fi
    le.getAbsolutePath());
476             }
477         } else {
```

```
478             System.out.println("File access cancelled by user.")
    ;
479         }
480         miNoise.setEnabled(true);
481     }//GEN-LAST:event_miOpenActionPerformed
482 
483 private void HMMParametersActionPerformed(java.awt.event.ActionE
    vent evt) {//GEN-FIRST:event_HMMParametersActionPerformed
484 jDialog1.setVisible(rootPaneCheckingEnabled);// TODO add your ha
    ndling code here:
485 jDialog1.setSize(487, 250);
486 jDialog1.setTitle("Transition probabilities");
487 }//GEN-LAST:event_HMMParametersActionPerformed
488 
489 private void fileChooserActionPerformed(java.awt.event.ActionEve
    nt evt) {//GEN-FIRST:event_fileChooserActionPerformed
490 // TODO add your handling code here:
491 }//GEN-LAST:event_fileChooserActionPerformed
492 
493 private void jMenu1MenuDeselected(javax.swing.event.MenuEvent ev
    t) {//GEN-FIRST:event_jMenu1MenuDeselected
494 // TODO add your handling code here:
495     repaint();
496 }//GEN-LAST:event_jMenu1MenuDeselected
497 
498     private void formMouseClicked(java.awt.event.MouseEvent evt)
    {//GEN-FIRST:event_formMouseClicked
499         // TODO add your handling code here:
500     }//GEN-LAST:event_formMouseClicked
501 
502     private void jButton4ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton4ActionPerformed
503         // TODO add your handling code here:
504         jDialog1.dispose();
505     }//GEN-LAST:event_jButton4ActionPerformed
506 
507 
508 
509     private void jButton1ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton1ActionPerformed
510         //Read transition probabilities
511         int x, y;
512         String temp;
```

```
513          for(x=0;x<num_states;x++)
514              for(y=1;y<=num_states;y++)
515              {
516                 temp=(jTable1.getValueAt(x,y)).toString();

517                 transition_probabilities[x][y-
    1]=Double.valueOf(temp).doubleValue();
518              }
519          jDialog1.dispose();
520      }//GEN-LAST:event_jButton1ActionPerformed
521
522
523
524      private void jButton5ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton5ActionPerformed
525          // Read noise probabilities
526          int x, y;
527          String temp;
528          for(x=0;x<num_states;x++)
529              for(y=1;y<=num_states;y++)
530              {
531                 temp=(jTable2.getValueAt(x,y)).toString();

532                 noise_probabilities[x][y-
    1]=Double.valueOf(temp).doubleValue();
533              }
534          calculate_state_probabilities();
535          jDialog2.dispose();
536
537
538      }//GEN-LAST:event_jButton5ActionPerformed
539
540      private void jButton8ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton8ActionPerformed
541          // TODO add your handling code here:
542          jDialog2.dispose();
543      }//GEN-LAST:event_jButton8ActionPerformed
544
545      private void miNoiseActionPerformed(java.awt.event.ActionEve
    nt evt) {//GEN-FIRST:event_miNoiseActionPerformed
546          // TODO add your handling code here:
547      jDialog2.setVisible(rootPaneCheckingEnabled);
548      jDialog2.setSize(487, 250);
```

```
549         jDialog2.setTitle("Set Noise Parameters");
550         }//GEN-LAST:event_miNoiseActionPerformed
551 
552         private void jButton2ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton2ActionPerformed
553             // Check box to enable exhaustive search decoding or Vit
    erbi decoding
554 
555             jButton1ActionPerformed(evt);
556 
557             if(jCheckBox1.isSelected()==true)
558             {
559                 calculateHMM_Viterbi();
560             }
561             else
562             {
563                 calculateHMM();
564             }
565 
566         }//GEN-LAST:event_jButton2ActionPerformed
567 
568         private void jMenu1MenuSelected(javax.swing.event.MenuEvent
    evt) {//GEN-FIRST:event_jMenu1MenuSelected
569             // TODO add your handling code here:
570             if(file_opened==0)
571             {
572                 miNoise.setEnabled(false);
573                 HMMParameters.setEnabled(false);
574             }
575             file_opened=1;
576         }//GEN-LAST:event_jMenu1MenuSelected
577 
578         private void jButton3ActionPerformed(java.awt.event.ActionEv
    ent evt) {//GEN-FIRST:event_jButton3ActionPerformed
579             // TODO add your handling code here:
580             jDialog3.dispose();
581         }//GEN-LAST:event_jButton3ActionPerformed
582 
583 
584 
585         void calculate_state_probabilities()
586         {
587             //Set HMM state probabilities
```

```
588             int x, y;
589             double temp=0;
590 
591             for(y=0;y<num_measurements;y++)
592             {
593                 for(x=0;x<num_states;x++)
594                 {
595                     state_probabilities[x][y]=noise_probabilities[no
    ise_measurements[y]][x];
596                 }
597             }
598             HMMParameters.setEnabled(true);
599 
600         }
601 
602 
603 
604         void toggleHMMs() {
605             // Can be used to hide or show the HMM filter series. Cu
    rrently unused
606             if(toggled==0)
607             {
608                 jLabel3.setText("Filtered measurements: ");
609                 jLabel4.setText("Filtered measurements (Viterbi):  "
    );
610                 toggled=1;
611             }
612                 else
613                 {
614                     toggled=0;
615                     jLabel3.setText(null);
616                     jLabel4.setText(null);
617                 }
618         }
619 
620 
621 
622         void calculateHMM_Viterbi()
623         {
624             // Viterbi decoding
625             int counter1, counter2, counter3;
626             double tmp[][], temp=0.0, max_value=0.0, temp1, temp2, t
    emp3;
```

```
627          int output_path[], current_path[];
628
629          output_path=new int[num_measurements]; //The
630          current_path=new int[num_measurements];
631          tmp=new double[num_states][num_measurements];
632
633          String path=new String();
634          long start = System.nanoTime();
635
636          for(counter1=0;counter1<num_measurements;counter1++) //I
    nitializations
637          {
638             output_path[counter1]=-1;
639             current_path[counter1]=-1;
640             for(counter2=0;counter2<num_states;counter2++)
641             {
642                  best_path[counter2][counter1]=-1;
643                  tmp[counter2][counter1]=state_probabilities[coun
    ter2][counter1];
644             }
645          }
646
647
648
649          for(counter1=1;counter1<num_measurements;counter1++) //I
    dentify the best path to each state for each measurement
650          {
651              for(counter2=0;counter2<num_states;counter2++)
652              {
653                  max_value=0.0;
654                  for(counter3=0;counter3<num_states;counter3++)
655                  {
656                      temp=tmp[counter3][counter1-
    1]*transition_probabilities[counter3][counter2];
657
658                      if(temp>max_value)
659                      {
660                          max_value=temp;
661                          best_path[counter2][counter1]=counter3;
    //Memorize the previous node for the best path to the current on
```

```
e
662                     }

663                  }
664                  tmp[counter2][counter1]*=max_value;
665              }
666          }
667
668
669
670         max_value=0;
671         temp=-1;
672
673         for(counter2=0;counter2<num_states;counter2++) //Find the
    best path for the st of paths to each state of the final measure
    ment
674         {
675             counter1=num_measurements-1;
676             current_path[counter1]=counter2;
677             temp3=state_probabilities[counter2][counter1];
678
679             while((best_path[current_path[counter1]][counter1]>-
    1)&&(counter1>0))
680             {
681                 temp1=state_probabilities[best_path[current_path[
    counter1]][counter1]][counter1-1];
682                 temp2=transition_probabilities[best_path[current_
    path[counter1]][counter1]][current_path[counter1]];

683                 temp=temp1*temp2*temp3;
684                 current_path[counter1-
    1]=best_path[current_path[counter1]][counter1];
685                 counter1--
    ;

686             }
687
688            if((temp>max_value)&&(counter1==0))
689             {
690                 max_value=temp;
691                 for(counter3=0;counter3<num_measurements;counter3
    ++)
692                 {
```

```
693                     output_path[counter3]=current_path[counter3];
694                     HMM_measurements[counter3]=output_path[counte
    r3];
695                 }
696             }
697         }
698 
699 
700         for(counter1=0;counter1<num_measurements;counter1++)
701         {
702             path=path+String.valueOf(output_path[counter1]);
703             path=path+" ";
704         }
705 
706          jLabel4.setText("Filtered measurements (Viterbi): "+ pat
    h);
707 
708          double elapsedTime = System.nanoTime()-start;
709          elapsedTime/=Math.pow(10,6);
710 
711          jDialog3.setVisible(rootPaneCheckingEnabled);
712          jDialog3.setSize(200, 120);
713          jDialog3.setTitle("Viterbi decoder");
714          jLabel5.setText("Running time: "+String.valueOf(elapsedT
    ime)+" msec");
715          System.out.println(elapsedTime);
716     }
717 
718      void calculateHMM() {
719          //Exhaustive search decoding
720          long counter, num_paths;
721 
722          double max_value=0, temp=1.0, temp1, temp2;
723          int output_path[], current_path[],counter1;
724          boolean updated;
725          String path=new String();
726          output_path= new int[num_measurements];
727          current_path= new int[num_measurements];
728 
729          long start = System.nanoTime();
730 
731          num_paths=(long) Math.pow(num_states, num_measurements);
```

```
    //The number of all paths to exhaustively search
732
733         for(counter1=0;counter1<num_measurements;counter1++)
734         {
735             current_path[counter1]=0;
736         }
737
738         for(counter=0;counter<num_paths;counter++) //Search each
    path and find the best one
739         {
740             for(counter1=0;counter1<num_measurements;counter1++)

741             {
742                 if(counter1<num_measurements-1)
743                 {
744                     temp1=state_probabilities[current_path[count
    er1]][counter1];
745                     temp2=transition_probabilities[current_path[
    counter1]][current_path[counter1+1]];
746
747                     temp*=temp1*temp2;
748                 }
749                 else
750                 {
751                     temp1=state_probabilities[current_path[count
    er1]][counter1];
752                     temp*=temp1;
753                 }
754             }
755
756
757             if(temp>=max_value) //If true, this path is currentl
    y the best path
758             {
759                 max_value=temp;
760                 for(counter1=0;counter1<num_measurements;counter
    1++)
761                 {
762                    output_path[counter1]=current_path[counter1];

763                    HMM_measurements[counter1]=current_path[count
    er1];
764                 }
```

```
765                 }
766
767                 temp=1.0;
768                 counter1=num_measurements-1;
769
770                 while(current_path[counter1]+1>=num_states) //calcul
    ate the next path to check
771                 {
772                     current_path[counter1]=0;
773                     counter1--;
774                     if(counter1<0)
775                         break;
776                 }
777
778                 if(counter1>=0)
779                     current_path[counter1]++;

780             }
781
782
783             for(counter1=0;counter1<num_measurements;counter1++)
784             {
785                 path=path+String.valueOf(output_path[counter1]);
786                 path=path+" ";
787             }
788
789
790             jLabel3.setText("Filtered measurements:"+ path);
791
792             double elapsedTime = System.nanoTime()-start;
793             elapsedTime/=Math.pow(10,6);
794
795             jDialog3.setVisible(rootPaneCheckingEnabled);
796             jDialog3.setSize(230, 120);
797             jDialog3.setTitle("Exhaustive search decoder");
798             jLabel5.setText("Running time: "+String.valueOf(elapsedT
    ime)+" msec");
799             System.out.println(elapsedTime);
800
801         }
802
803         @Override
804         public void update(Graphics g) {
```

```
805             //g.drawImage(backbuffer, 0, menubar_height, this);
806         }
807 
808         @Override
809         public void paint(Graphics g) {
810             super.paint(g);
811             //update(g);
812         }
813 
814 
815         /**
816         * @param args the command line arguments
817         */
818         public static void main(String args[]) {
819             java.awt.EventQueue.invokeLater(new Runnable() {
820                 public void run() {
821                     new HMMFilter().setVisible(true);
822                 }
823             });
824     }
825     // Variables declaration - do not modify//GEN-BEGIN:variables
826         private javax.swing.JMenuItem HMMParameters;
827         private javax.swing.JFileChooser fileChooser;
828         private javax.swing.JButton jButton1;
829         private javax.swing.JButton jButton2;
830         private javax.swing.JButton jButton3;
831         private javax.swing.JButton jButton4;
832         private javax.swing.JButton jButton5;
833         private javax.swing.JButton jButton8;
834         private javax.swing.JCheckBox jCheckBox1;
835         private javax.swing.JDialog jDialog1;
836         private javax.swing.JDialog jDialog2;
837         private javax.swing.JDialog jDialog3;
838         private javax.swing.JFileChooser jFileChooser1;
839         private javax.swing.JInternalFrame jInternalFrame1;
840         private javax.swing.JLabel jLabel1;
841         private javax.swing.JLabel jLabel2;
842         private javax.swing.JLabel jLabel3;
843         private javax.swing.JLabel jLabel4;
844         private javax.swing.JLabel jLabel5;
845         private javax.swing.JMenu jMenu1;
846         private javax.swing.JMenuBar jMenuBar1;
847         private javax.swing.JPanel jPanel1;
```

```
848         private javax.swing.JScrollPane jScrollPane1;
849         private javax.swing.JScrollPane jScrollPane2;
850         private javax.swing.JTable jTable1;
851         private javax.swing.JTable jTable2;
852         private javax.swing.JMenuItem miClose;
853         private javax.swing.JMenuItem miDeviation;
854         private javax.swing.JMenuItem miNoise;
855         private javax.swing.JMenuItem miOpen;
856     // End of variables declaration//GEN-END:variables
857     }
```