

Automated collision detection using machine learning algorithms on sensor data

Project Report

from the Course of Studies Angewandte Informatik
at the Cooperative State University Baden-Württemberg Mannheim

by
Tim Schmidt

August 2018

Time of Project	17 weeks
Student ID, Course	8531806, TINF15AI-BC
Company	IBM Deutschland GmbH, Ehningen
Supervisor in the Company	Julian Jung
Reviewer	Julian Jung

Author's declaration

Hereby I solemnly declare:

1. that this Project Report, titled *Automated collision detection using machine learning algorithms on sensor data* is entirely the product of my own scholarly work, unless otherwise indicated in the text or references, or acknowledged below;
2. I have indicated the thoughts adopted directly or indirectly from other sources at the appropriate places within the document;
3. this Project Report has not been submitted either in whole or part, for a degree at this or any other university or institution;
4. I have not published this Project Report in the past;
5. the printed version is equivalent to the submitted electronic one.

I am aware that a dishonest declaration will entail legal consequences.

Mannheim, August 2018

Tim Schmidt

Contents

List of Figures	III
1 Introduction	1
1.1 Motivation	1
1.2 Objective	2
1.3 Limitations of the Research	2
1.4 Organization of the Research	3
2 Theory	4
2.1 Machine Learning	4
2.2 Classification	4
2.3 Evaluation of Classifiers	4
2.4 Algorithms	4
2.4.1 Linear support vector classifier	4
2.4.2 Logistic regression	5
2.4.3 Decision tree	5
2.4.4 Random forest	5
2.4.5 Gradient-boosted trees	5
2.4.6 Naive Bayes	5
3 Analysis of the pattern recognition problem	6
3.1 Analysis of the time series data	6
3.2 Solution strategy	7
4 Algorithm configuration	10
5 Evalutation	18
6 Reflection and outlook	20
Bibliography	22

List of Figures

3.1	Illustration of Sensorboard and axis of measurement. The driving direction is to the right.	7
3.2	Example data point in key-value-pair notation notation	8
3.3	Example of measured accelerations on 3 Axis during a collision	8
3.4	Distribution of data points labeled as collision (blue) or no collision (red) .	9
5.1	Ranking of classification algorithms	18

1 Introduction

1.1 Motivation

The field of data analytics and machine learning is increasingly becoming the main differentiator of industry competition. This is especially true in combination with another growing field, the Internet of Things (IoT). This is what the McKinsey Global Institute's study 'The Age of Analytics: Competing In A Data-Driven World' found. [1] IBM has set a goal to tackle the challenges of IoT and Big Data with an array of new services, industry offerings and capabilities for enterprise clients, startups and developers. [2] These services are part of IBM Bluemix, a cloud platform as a service (PaaS).

An important step for IBM is getting clients interested and aware of the capabilities of IoT and machine learning so that collaborations and projects with clients can be established. One way this is done is by presenting showcases – small projects that show the possibilities and values of the technology in an exemplary way. It is essential to show technologies from the IBM Bluemix portfolio to present their capabilities and outline differentiating factors to competitors.

The Sensorboard is such a showcase. A physical skateboard is equipped with a Texas Instrument's SensorTag and able to connect wirelessly to the IBM's Bluemix cloud platform. From there one or more Sensorboards can be monitored and managed. As part of the showcase the Sensorboard is demonstrated as a rentable and cloud-managed vehicle for urban mobility.

This showcase will be extended with machine learning applications to present the value machine learning algorithms can have on sensor data. The specific goal of that extension is to recognize collisions that happen to the Sensorboard and that indicate accidents. This recognition will be based solely on sensor data and patterns in the time series data. For this IBM Bluemix services are used to showcase the capabilities of the platform. There are services which are requested to be demonstrated and used in the showcase. This is the IBM IoT Foundation, used to connect the Sensorboard to the platform. Moreover the IBM Data Science Experience should be used as a development environment for an underlying Apache Spark cluster, on which machine learning models will can be created.

1.2 Objective

A consumer grade skateboard is equipped with a Texas Instrument's SensorTag. The Texas Instrument's SensorTag collects acceleration data from the skateboard on three spacial axis. To process this data cloud services of IBM Bluemix are used. This especially includes the IBM Data Science Experience and an Apache Spark service. Consequently utilizing Apache Spark as a framework for cluster computing, machine learning models are trained using Apache Spark. This narrows down the selection of machine learning algorithms to the algorithms available in function library Apache Spark MLlib, which provides scalable algorithms, optimized to run on Apache Spark.

This paper investigates on the feasibility of machine learning algorithms for collision detection in the above described setting and identifies, if feasible, the best performing algorithm under the described conditions.

The scenario of impact detection that may indicate accidents requires a higher focus on detecting an accident than on preventing false alarms. A metric is found to represents this unequal relationship in the assessment of algorithm performance.

1.3 Limitations of the Research

The technologies described - the Texas Instrument's SensorTag, the IBM Bluemix services and programming libraries - are a given for the project by IBM. Therefore the decisions for those and no other technologies will not be discussed and no evaluation of alternatives will be conducted in this paper.

The findings will only be acquired and applicable for the specific hardware and configuration described in the paper. Findings can not be transferred to other vehicles, sensors, configurations or any other setup than the one described.

The data which is used to come to decisions and to train models is generated in experiments, which are conducted solely for this reason. No other sensor data of skateboards or other vehicles are used in the considerations of this paper. The machine learning algorithms examined only include algorithms currently provided by the function library Apache Spark MLlib. A list of relevant algorithms currently provided can be seen in the appendix in chapter ??.

1.4 Organization of the Research

The chapter 'Theory' introduces the topic of machine learning. Relevant machine learning algorithms and evaluators are explained with sufficient theoretical and mathematical background information. The goal of the chapter is to create a basic understanding for methods and metrics this paper investigates.

In the following chapter 'Analysis of the pattern recognition problem', the pattern recognition problem will be analysed in detail. The goal of the chapter is to define specific possible solutions for the problem.

The chapter 'Algorithm configuration' brings together the theoretical knowledge about machine learning and possible solution strategies. It is shown how algorithms are best configured and applied for the problem. The goal of the chapter is to generate a comparable result for the different possible solutions.

In the chapter 'Evaluation', the results are then compared to each other. The goal of this chapter is to answer the question of whether machine learning algorithms are feasible for collision detection. If feasible, a winning solution that is best performing under the considered conditions is identified. A conclusions about the results is drawn.

In the end, the chapter 'Reflection and outlook' gives presents a critical reflection of the results and a proposal on possible further research and development.

2 Theory

2.1 Machine Learning

Supervised unsupervised: <http://ai.stanford.edu/people/nilsson/MLBOOK.pdf> 6

features

2.2 Classification

classification, input, representation, hypothesis, generalization:

classification application in pattern recognition

2.3 Evaluation of Classifiers

- f-score fscore , precision, recall (2 oben rechts)
- Cross validation

especially k-fold validation: is non exhaustive

2.4 Algorithms

- hyper-parameters

2.4.1 Linear support vector classifier

(Linear SVM = Support Vector Classifier für Spark MLlib)

An introduction to statistical learning maximal margin classifier -> the support vector classifier -> +maximal margin classifier

2.4.2 Logistic regression

D. R. Cox, The Regression Analysis of Binary Sequences 1958

2.4.3 Decision tree

2.4.4 Random forest

2.4.5 Gradient-boosted trees

2.4.6 Naive Bayes

info PDF in quellen

3 Analysis of the pattern recognition problem

3.1 Analysis of the time series data

This chapter will provide a closer examination of the time series data measured by the Texas Instrument's SensorTag. This data is prerequisite for the further work of this paper. The sensor data is measured and collected at a sampling rate of 10 measurements per second. To optimize accuracy the maximal sampling rate of the Texas Instrument's SensorTag was chosen. The measurements include acceleration in 3 spacial axis. The axis each correspond to a direction on the Sensorboard and are orthogonal to each other as shown in figure 3.1. The acceleration is measured in g, which refers to the acceleration that is imparted by the gravity of earth. For g the following conversion to m/s^2 holds true: $1g = 9.80665m/s^2$.

The acceleration in any particular direction will be referred to as x, y or z acceleration.

Those measurements are taken simultaneously and handled from then on together as one measurement collection. This collection is enriched with the time of the measurement in form of a Unix timestamp.

A measurement collection as described above will also be referred to as a data point. A single measurements (for instance x acceleration) of a data point will be also referred to as features of that data point.

An exemplary data point in a key-value-pair format can be seen here in figure 3.2.

The keys stand for acceleration in x direction, acceleration in y direction, acceleration in z direction and the Unix timestamp when the measurement took place.

Using the time of measurement, data can be plotted on a time axis plot as seen in figure 3.3.

With this, the Sensorboard data has been collected. During the testing of the Sensorboard 69 collisions were simulated. Accordingly, 69 of the 6453 datapoints collected, were labeled as a collision while the rest was labeled as no collision. The labeling was implemented by analysing video footage recorded during the test drive. The exact time of a collision in the video was matched with the time of the recorded sensor data to label data points correctly. The distribution of the data points labeled as collision or no collision can be seen in figure

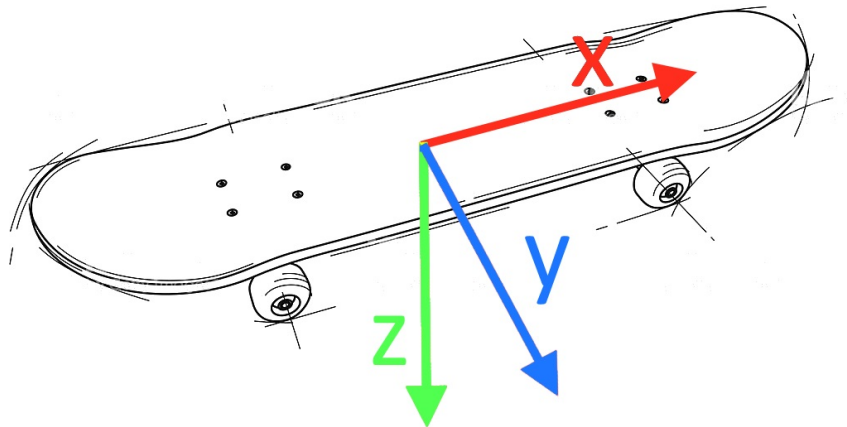


Figure 3.1: Illustration of Sensorboard and axis of measurement. The driving direction is to the right.

3.4. The scatter plot shows the relationship between the x and z acceleration and the label of the data point. A blue data point represent a collision the red data points represent no collision.

3.2 Solution strategy

Combining the knowledge about the sensor data from the previous section and the objective as described in chapter 1, this chapter will narrow down on a specific problem type and solution strategy. In the process, the limitations described in Chapter 1 have to be considered.

A corpus of sensor data was collected as described above and labelled according to the event of a collision or no collision. In chapter 1 the necessity of using the Apache Spark library module 'MLlib' is constituted.

Having a set of prelabeled sensor data allows for a supervised machine learning approach. Furthermore the existence of concrete data points which represent the state of the Sensorboard at a given time makes it possible to base the recognition of collisions solely on data points. The recognition of collisions can then in turn be formulated as the problem of

```
{  
  "accx": -0.079590,  
  "accy": 0.001465,  
  "accz": -1.016602,  
  "time": 1502735960911  
}
```

Figure 3.2: Example data point in key-value-pair notation notation

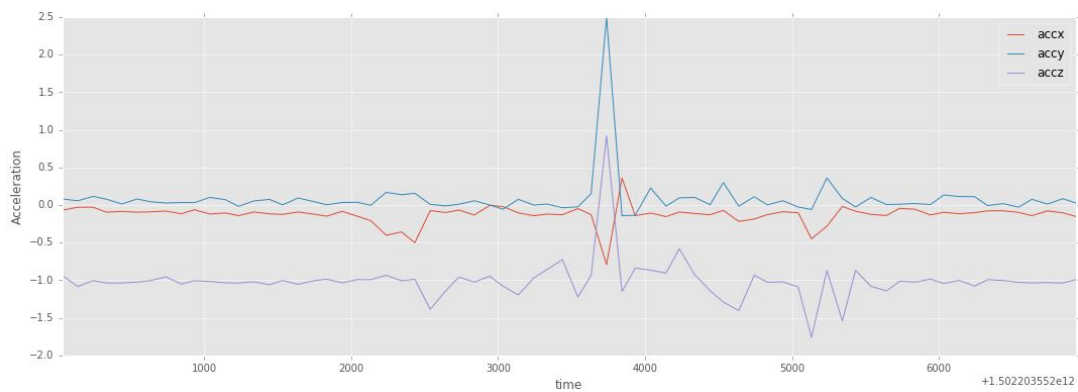


Figure 3.3: Example of measured accelerations on 3 Axis during a collision

deciding whether a given data point corresponds to a collision or no collision. A problem of this kind can be solved by binary classification.

Having specified the solution method to a binary classification approach, specific algorithms can be considered. For the specific task of supervised binary classification the following algorithms are supported by the MLlib module:

- Linear SVM
- Logistic regression
- Decision tree
- Random forest
- Gradient-boosted trees
- Naive Bayes

Only the possible algorithms mentioned here will be parameterized and trained on the collected data in chapter 4.

To assess the performance of resulting models a clear metric will be used for comparison. This metric has to represent the unequal importance of detecting a collision and preventing false alarms. As mentioned in chapter 1 the act of detecting a collision that actually happened (*true positives*) is more important than preventing the detection of a collision

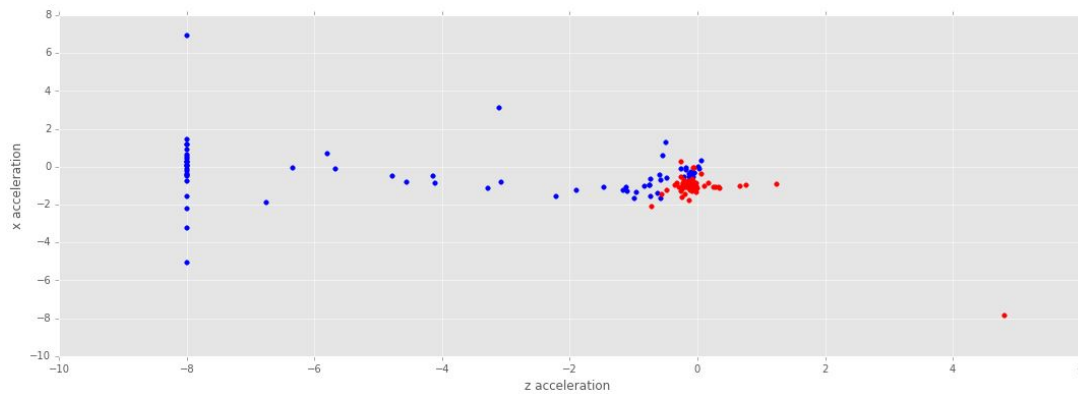


Figure 3.4: Distribution of data points labeled as collision (blue) or no collision (red)

that didn't happen (*false positives*). In a classification setting the effectiveness in detecting collision that actually happened is described by recall. The effectiveness of preventing the detection of collision that didn't happen is described by precision. The metric that will be used to represent the unequal relationship between precision and recall is a f_2 -score. This metric puts more weight on the recall of a model. This way a later evaluation of trained classifiers can be done based on one correctly weighted metric.

4 Algorithm configuration

Many of the methods proposed in chapter 3 require *hyper-parameters* that vary aspects of the algorithm and might lead to better or worse results. To ensure that all the algorithms are comparable with each other this chapter goes over the process of finding the optimal hyper-parameters for every approach. A comparable score is assigned to every algorithm under the condition of optimal hyper-parameters.

Hyper-parameter tuning

The process of searching and finding good hyper-parameters for a given algorithm is called hyper-parameter tuning. Searching for good hyper parameters takes the following aspects to be considered:

- **an estimator**

The estimator in this case is a binary classifier. The 8 different binary classifiers have to be considered as mentioned in chapter 3.

- **a parameter space**

The parameter space defines a set of parameters or combination of parameters that will be tested. From this set one element will be chosen as most fitting. Because every algorithm requires different parameters, the parameter space is different for every algorithm. The parameter space will be defined in the sections below for every algorithm.

- **a method for searching or sampling candidates**

The method that is chosen is grid search. Grid search is a brute force search, which uses an exhaustive searching through a defined parameter space. Models are iteratively trained and evaluated by a score function. The model scores are then compared. The hyper-parameters that produced the best performing model will be chosen as optimal ones for the algorithm.

- **a cross-validation scheme**

The cross-validation scheme used is a k-fold validation, with $k=10$.

- **a score function**

As mentioned in chapter 3 a f_2 -score will be used to evaluate the models in the end. Our goal for the hyper-parameter tuning is thereby also to maximise the f_2 -score. For that reason the f_2 -score is used as a score function.

For the hyper-parameter search no external functions or libraries are used. The search algorithm is implemented in the following way.

For a given estimator (in this case one of the possible classification algorithms) the parameter space is defined manually for every hyper-parameter of a given estimator.

Models are now repeatedly trained by iterating through every combination of hyper-parameters in the parameter spaces.

For every trained model a k-fold validation, with $k=10$, is performed.

During the k-fold validation, the f_2 -score is calculated.

After this process is done the hyper-parameters that resulted in the highest f_2 -score are chosen.

For the each of the relevant algorithms a parameter space will be defined. The results of the hyper parameter search will then be presented.

Linear SVM

The tunable hyper-parameters for the the linear SVM classifier is the regularization.

L1 regularization:

$$\sum_{i=1}^n |y_i - f(x_i)|$$

y_i is the target value and x_i is the estimated value for y_i .

L1 regularization is a loss function that minimizes the sum of the absolute differences of target and estimated value.

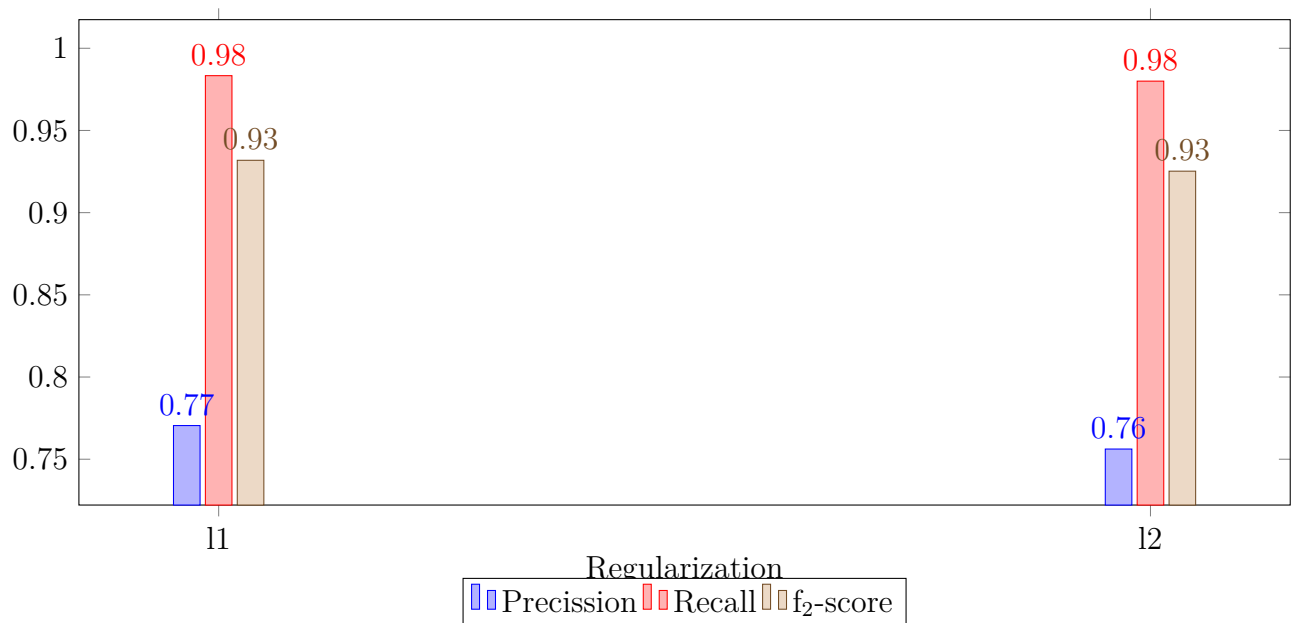
L2 regularization:

$$\sum_{i=1}^n (y_i - f(x_i))^2$$

y_i is the target value and x_i is the estimated value for y_i .

L2 regularization is a loss function that minimizes the square of the absolute differences of target and estimated value.

The hyper-parameter search reveals the following results for the two regularization approaches:



The best performing SVM model reaches a maximal f₂-score of **0.93** (precision: 0.77, recall: 0.98) with the following hyper-parameter:

Regularization: **l1 regularization**

Logistic regression

The tunable hyper-parameters for the the logistic regression classifier is the regularization.

L1 regularization:

$$\sum_{i=1}^n |y_i - f(x_i)|$$

y_i is the target value and x_i is the estimated value for y_i .

L1 regularization is a loss function that minimizes the sum of the absolute differences of target and estimated value.

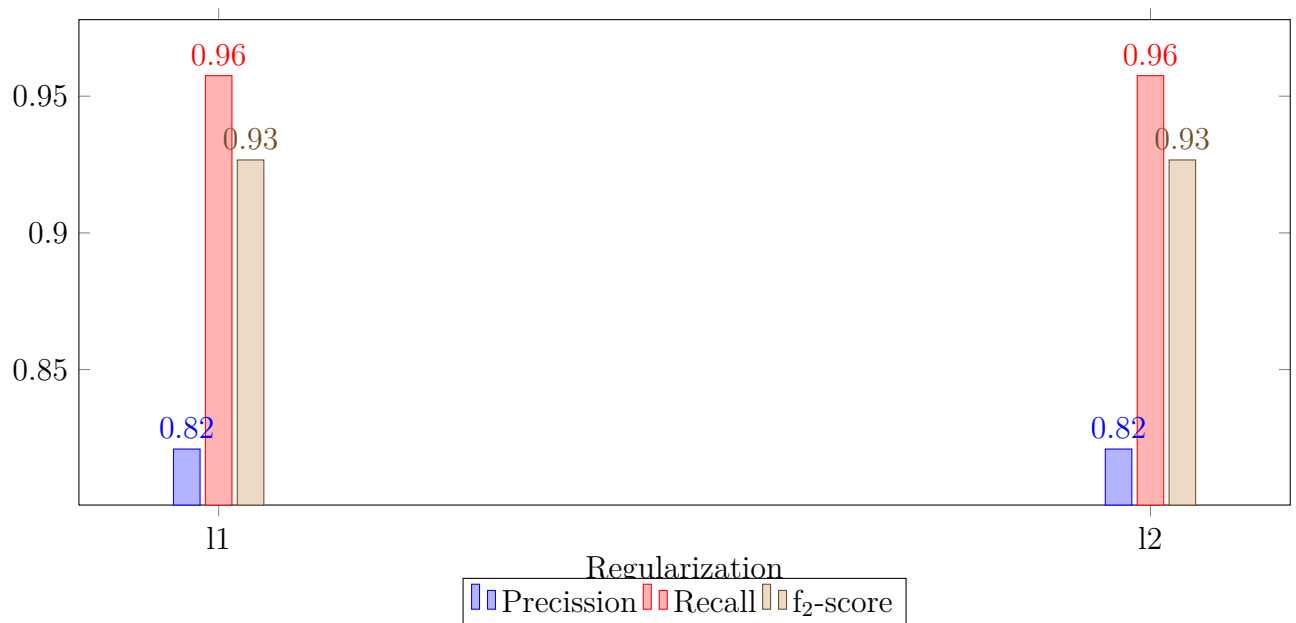
L2 regularization:

$$\sum_{i=1}^n (y_i - f(x_i))^2$$

y_i is the target value and x_i is the estimated value for y_i .

L2 regularization is a loss function that minimizes the square of the absolute differences of target and estimated value.

The hyper-parameter search reveals the following results for the two regularization approaches:



The best performing logistic regression model reaches a maximal f_2 -score of **0.93** (precision: 0.82, recall:0.95) independent of which regularization is used.

Decision tree

The tunable hyper-parameters for the decision tree algorithm are:

- **Impurity**

The impurity measure is used to decide on a splitting rule for each node in the decision tree building process. Two impurity measures for classification are provided:

Gini impurity:

$$\sum_{i=1}^C f_i(1 - f_i)$$

C is the number of unique labels and f_i is the frequency of label i in a node.

Entropy:

$$\frac{1}{N} \sum_{i=1}^C -f_i \log(f_i)$$

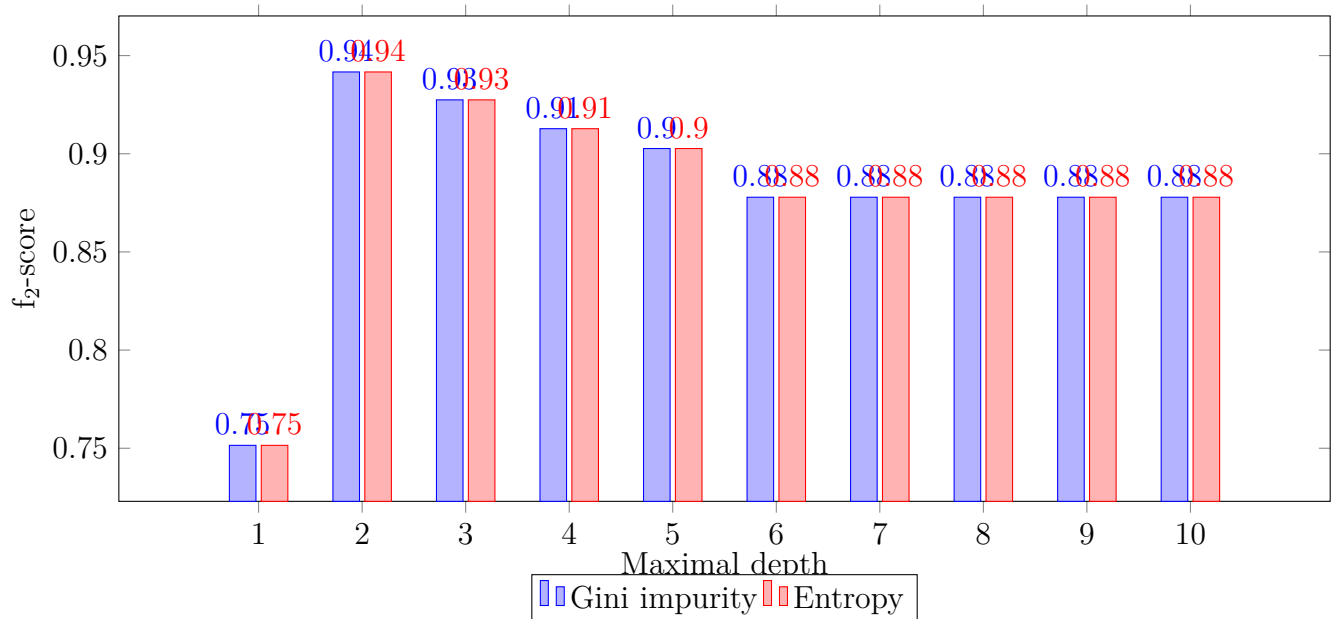
C is the number of unique labels and f_i is the frequency of label i in a node.

- **Maximal depth**

The maximal depth determines a limit of growth for a decision tree. This consequently limits the number of nodes or decisions that are possible. It represents a stopping criteria.

The parameter space for the maximal depth is chosen **from 1 to 10** (inclusive).

The hyper-parameter search reveals the following results:



The best performing decision tree model reaches a maximal f₂-score of **0.94** (precision: 0.92, recall: 0.96) with the following hyper-parameters:

Impurity: **Ginni Impurity or Entropy**

Maximal depth: **2**

Random forest

The tunable hyper-parameters for the random forest classifier are:

- **Number of trees**

The number of trees that are build during the training phase to act as an ensemble of (randomized) decision trees.

The parameter space for the number of threes is chosen **from 2 to 10** (inclusive).

- **Impurity**

The impurity measure is used to decide on a splitting rule for each node in the decision tree building process. Two impurity measures for classification are provided:

Gini impurity:

$$\sum_{i=1}^C f_i(1 - f_i)$$

C is the number of unique labels and f_i is the frequency of label i in a node.

Entropy:

$$\frac{1}{N} \sum_{i=1}^C -f_i \log(f_i)$$

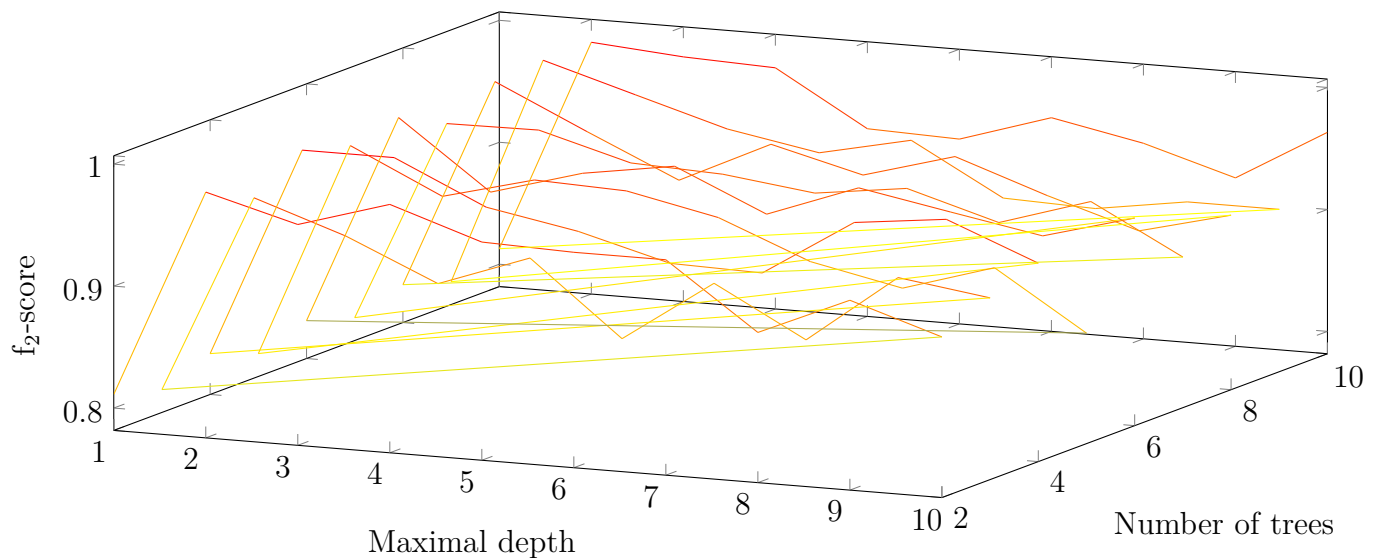
C is the number of unique labels and f_i is the frequency of label i in a node.

- **Maximal depth**

The maximal depth determines a limit of growth for a decision tree. This consequentially limits the number of nodes or decisions that are possible. It represents a stopping criteria.

The parameter space for the maximal depth is chosen **from 1 to 10** (inclusive).

The hyper-parameter search reveals the following results:



The best performing decision tree model reaches a maximal f_2 -score of **0.99** (precision: 0.94, recall: 1.0) with the following hyper-parameters:

Number of trees: **4**
 Impurity: **Entropy**
 Maximal depth: **2 or 3**
 or
 Number of trees: **9 or 10**
 Impurity: **Entropy**
 Maximal depth: **2**

Gradient-boosted trees

The tunable hyper-parameters for the decision tree algorithm are:

- **Loss function**

The loss function is used for minimization during gradient boosting. The loss function provided are:

LogLoss

Least Squares Error

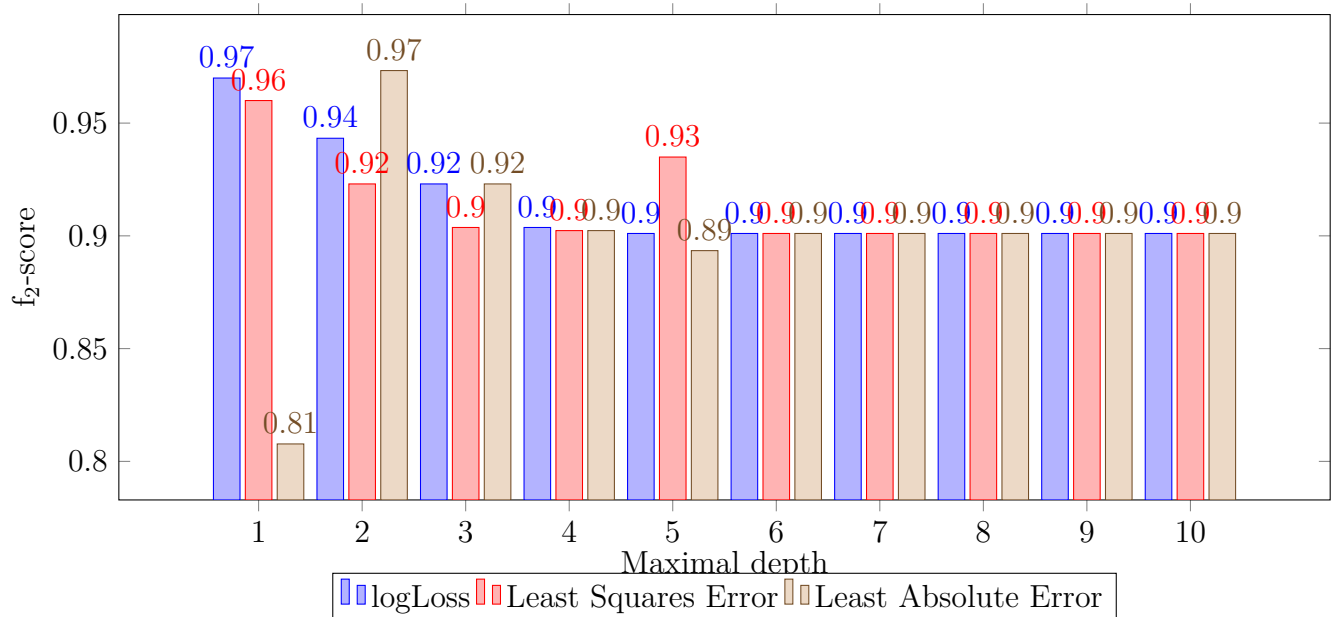
Least Absolute Error

- **Maximal depth**

The maximal depth determines a limit of growth for a decision tree. This consequently limits the number of nodes or decisions that are possible. It represents a stopping criteria.

The parameter space for the maximal depth is chosen **from 1 to 10** (inclusive).

The hyper-parameter search reveals the following results:



The best performing Gradient-boosted tree classifier reaches a maximal f_2 -score of **0.97** (precision: 0.96, recall: 0.98) with the following hyper-parameters:

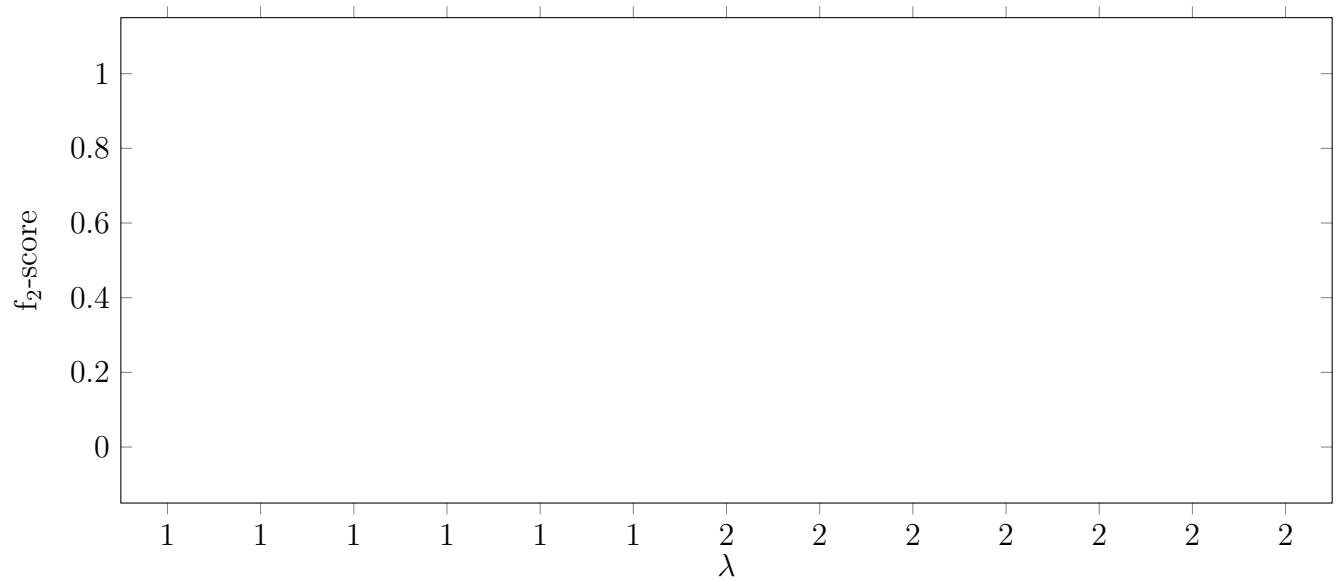
Loss function: **Least Absolute Error**

Maximal depth: **2**

Naive Bayes

The tunable hyper-parameters for the the Naive Bayes classifier is a λ -value used for additive smoothing. The parameter space for λ is chosen **from 0.1 to 10.0** (inclusive).

The hyper-parameter search reveals the following results for the two regularization approaches:



The best performing naive bayes classifier reaches a maximal f_2 -score of (precision: , recall:) with the hyper-parameter:

λ :

5 Evalutation

The optimal configuration for the different algorithms has been worked out in chapter 4. Now this chapter is devoted to comparing and deciding on an optimal algorithm for the problem of collision detection.

To be able to compare the algorithms they are each used to train a model with the hyper-parameters found in chapter 3. The models are evaluated with a k-fold validation, with $k=10$. The results can be seen in figure 5.1.

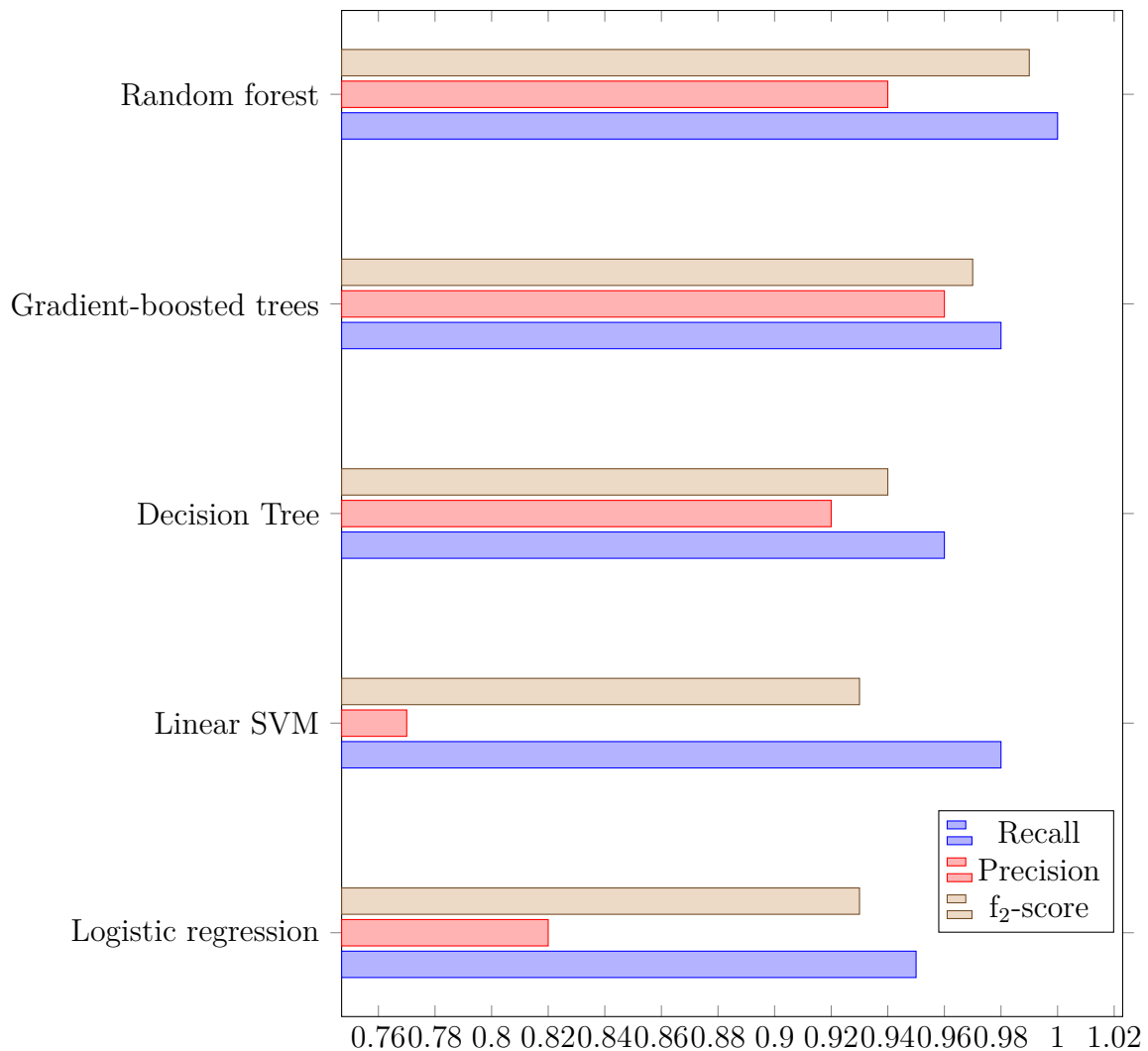


Figure 5.1: Ranking of classification algorithms

According to the f_2 -score the best performing method is a random forest classifier with 4 equally well performing hyper-parameter configurations:

Number of trees: 4	Impurity: Entropy	Maximal depth: 2
Number of trees: 4	Impurity: Entropy	Maximal depth: 3
Number of trees: 9	Impurity: Entropy	Maximal depth: 2
Number of trees: 10	Impurity: Entropy	Maximal depth: 2

The best performing random forest model reaches a maximal f_2 -score of **0.99** (precision: 0.94, recall: 1.0).

This means a collisions that occur will be classified correctly classified as a collision 100% of the time on the collected data and will be falsely classified as a collision 6% of the time when no actual collision happened.

This results indicate that the machine learning approach to recognizing collisions on a physical board is eligible and can perform well. Still it has to be considered that these results are achieved on data which is generated in experience soly for that reason and results may differ when applied in real world situations.

In figure 5.1 the ranking of the classification methods shows that decision tree based approaches have a advantage over the remaining algorithms. Random forest and gradient-boosted tree models as decision tree assembles performed on average better than a single decision tree.

6 Reflection and outlook

The previous chapter reached the conclusion that machine learning algorithms are, in fact, feasible for detecting collision detection in the case of the Sensorboard. This shows the potential that machine learning algorithms might have for detecting patterns corresponding to driving behaviours or incidents.

Regardless of the positive result, this study has to be viewed critically. The process of building models and evaluating them is based on datasets generated in experiments in isolated conditions. As no real driving data was recorded in the dataset, the outcome of the research might not be completely transferable to a real driving scenario. Conditions like rough or irregular surfaces and unexpected driving manoeuvres will influence the data quality and therefore the model consistency.

Furthermore the results of this study can not be applied to other driving scenarios as patterns in data will differ based on the vehicle and might not be recognized as easily or with the same methods as described in this paper.

Nevertheless the results of the research clearly indicate potential of this approach for similar use cases. The knowledge gained regarding the feasibility and best methods for a machine learning approach to this use case points further research in the right direction. In further research the results of this paper can be refined and checked by using sensor data originating from real driving of the Sensorboard as it resembles more realistic driving behaviour. This way the result can be applied to more realistic conditions.

In addition the experimental results of this study can be further examined. It can be studied why some algorithms perform better than the others in the given scenario. The fact that tree based algorithms seem to work better here might be explained by the non linearity of the models created. In contrast the linear SVM and logistic regression represent generate linear models. The superiority of decision tree assemblies like the Random forest and gradient-boosted tree over a single decision tree might be explained by a reduction in variance of a classifier and thereby prevention of overfitting and better generalization of the models. A definite explanation for those phenomenon can be explored in further research.

Furthermore the knowledge gained during this research can transposed on other similar problems. Other vehicles like bikes, motorbikes or cars might as well allow for a machine learning based detection of events like collisions.

Even when applied only to a showcase scenario as in this paper, it becomes clear that machine learning applied to IoT data has a lot of potential. Being able to showcase this fact to clients will lead them to a smarter way of making use of sensor data in the

information age. In this way the growing field of the Internet of Things in combination with machine learning might have an even bigger impact on industries and consumers.

Bibliography

- [1] R.S. Michalski, J.G. Carbonell, T.M. Mitchell. Machine Learning: An Artificial Intelligence Approach. <https://books.google.de/books?hl=de&lr=&id=-eqpCAAQBAJ&oi=fnd&pg=PA2&dq=study+on+potential+of+machine+learning&ots=Wl-OMF6Ji-&sig=d1L-cfXoFQlv0TbHk1pj18Q6rsA#v=onepage&q=study%20on%20potential%20of%20machine%20learning&f=false>, Zugriff 20.08.2017