

Feature and Sensor Selection for Detection of Driver Stress

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Abstract: This study presents a real-life application-based feature and sensor relevance analysis for detecting stress in drivers. Using the MIT Database for Stress Recognition in Automobile Drivers, the relevance of various physiological sensor signals and features for distinguishing the driver's state have been analyzed. Features related to heart rate, skin conductivity, electromuscular activity, and respiration have been compared using filter and wrapper selection methods. For distinguishing rest from activity, relevant sensors have been found to be heart rate, skin conductivity, and respiration (giving up to 94.6 ± 1.9 % accuracy). For distinguishing low stress from high stress, relevant sensors have been found to be heart rate and respiration (giving up to 78.1 ± 4.1 % accuracy). In both cases, a multi-user model that requires only a calibration from the user in rest, without prior knowledge of the user's individual stress dynamics, resulted in a different optimal sensor and feature configuration, giving 87.3 ± 2.8 % and 72.1 ± 4.3 % accuracy respectively.

1 INTRODUCTION

Driving a vehicle is a part of many people's daily life, which can generate a variety of stressful situations. Examples are social stress from other nearby drivers and time pressure due to the necessity of taking quick driving decisions. Too great driver stress levels might encourage aggressive driving, such as road rage (Hennessy and Wiesenthal, 1999), exposing the driver and other traffic for risk of physical harm. A part of the solution to this problem is to automatically detect the mental state of the driver using non-invasive sensors. Depending on the driver's stress state, the car could automatically adapt e.g. the user interface and the music, and advice the driver differently (Hernandez et al., 2014).

Common physiological signals for detecting driver stress include electrodermal activity (EDA), electrocardiogram (ECG), electromuscular activity (EMG), and respiration (Resp) (Rigas et al., 2012), (Healey and Picard, 2000). Other examples are video recordings tracking facial expressions (Gao et al., 2014), speech (Bořil et al., 2009), the CAN bus of the vehicle (Bořil et al., 2009), (Rigas et al., 2012), and GPS information (Rigas et al., 2012). A review of several studies on driver stress, comparing systems

and signals for monitoring can be found in (Singh and Queyam, 2013). Examples of other sensors and signals that have been tried for stress detection are skin temperature, eye tracking and pupil diameter (Palinko et al., 2010), and behavioural measures such as gestures and accelerometer data.

In this study, the signals of the MIT Stress Recognition in Automobile Drivers Database (Healey and Picard, 2008) have been analyzed to determine which ones best distinguish the mental state of the driver in rest versus driving, and highway versus city driving. (Healey and Picard, 2005), (Akbas, 2011), (Queyam, 2013), and (Yong Deng, 2013) analyzed the same database and reached up to 94.7 % of correct classification for different configurations.

We emphasize on the design of an automatic state detector using physiological sensors. We consider two classification problems: distinguishing rest from activity, and low stress from higher stress. Calibration is a critical point when developing such a system. Most of the previous studies consider samples from all drivers in both the training and the validation steps. This supposes a use case where data from a period when the subject is resting and from when the subject is stressed is available, letting the model adapt to individual stress dynamics by training a dif-

ferent model for each person (single-user). This calibration allows for high precision, however it is very constraining, which makes it less useful for real-life applications. In a final application it could also require embedding the training part of a machine learning algorithm. For these reasons, we also consider a more realistic calibration case: multi-user. This case creates one universal model, which would only require calibration from a resting period (for removing individual baselines). This is more feasible in a real-life situation, but it demands a more general model than the single-user case.

Within this scope, we focus on selecting the set of sensors and signal features that most accurately predicts driver stress. Firstly, the data is presented in Section 2. Secondly, the classification problem is defined in Section 3. Thirdly, all the features and their physiological meaning are explained Section 4. Subsequently, Section 5 gives an overview of all the feature selection methods used in this study. Finally, Section 6 presents and discusses the results, while Section 7 concludes this work.

2 THE DRIVE DATABASE

The MIT Stress Recognition in Automobile Drivers Database (Healey and Picard, 2008) consists of physiological data originating from drivers in the state of rest, highway driving, or city driving. It contains a total of 16 data sets (drives), where 7 signals have been recorded: ECG at 496 Hz, HR at 15.5 Hz, EMG at 15.5 Hz (placed at the left shoulder), SC at 31 Hz (placed at left foot and hand), and respiration at 31 Hz. Additionally, there is a marker signal, which indicates the phase of the experiment. Due to various acquisition problems being present in some of the data sets, only 9 of the drives were analyzed in this study.

3 CLASSIFICATION PROBLEM

The marker signal was used to separate the six phases of the experimental phase, specified in Table 1. Figure 1 gives an example of the signals, for the Drive 15 data set. The start of the six phases are identified by a red vertical line. In this study, the phases were grouped in two different ways. The first one, rest vs. driving (RvsD) uses the data from the initial rest to define the class “rest” (R), and the data from all city and highway phases to define the class “drive” (D). This corresponds to distinguishing a person that is resting from when the person is doing an activity. The second way of grouping the phases is highway vs.

Table 1: The six phases of each drive, their abbreviation and their mean durations with standard deviation.

Phase	Abbr.	Duration $\mu \pm \sigma$
Initial rest	R_1	15 m 7 s \pm 21 s
City drive 1	C_1	14 m 59 s \pm 2 m 5 s
Highway drive 1	H_1	7 m 59 s \pm 1 m 14 s
City drive 2	C_2	6 m 50 s \pm 1 m 47 s
Highway drive 2	H_2	7 m 17 s \pm 28 s
City drive 3	C_3	11 m 23 s \pm 3 m 0 s

city (HvsC). In this case, the first class consists of all highway drives, and is called “highway” (H), while the class “city” (C) consists of all city drives. The idea of distinguishing between these states is based upon the assumption that people find it more stressful to drive in a city environment than on the highway. This was confirmed by the questionnaires in (Healey and Picard, 2005, p. 159).

4 FEATURES

The mean HR, along with HRV features measure the variations of the inter-beat intervals (IBI) of an ECG, and are known as relevant stress indicators (Sun et al., 2010, p. 3). Activation of the sympathetic nervous system ensures a more regular heart beat, which is why features such as the root mean square (RMS) of the difference between successive IBI are expected to decrease in stressful situations. Similarly, HRV power spectrum features are relevant, especially the low frequency component, regulated by both the sympathetic and parasympathetic nervous system, and the high frequency component, regulated by the parasympathetic nervous system. Their ratio is used as an index of the balance between the two nervous systems, and is expected to decrease with increasing stress.

Another widely used measure in stress detection is the electrodermal activity, which can be recorded using electrodes that measure the skin conductivity (SC) or the skin resistance between so called active sites on the inner surface of the hands or the feet. In this work, the skin conductivity will be used. The SC is purely regulated by the sympathetic nervous system, and manifests itself by an increase in skin conductance level in stressful conditions, with rapidly rising peaks that slowly return to base level (Kappeler-Setz et al., 2010). Thus for detecting stress, features such as the mean SC and features for distinguishing the rising and falling parts of the signals (e.g. the mean of the absolute derivative and proportions of positive samples in derivative) can be used.

Furthermore EMG activity, e.g. in the trapezoid muscle (Lundberg et al., 1994) are known to increase

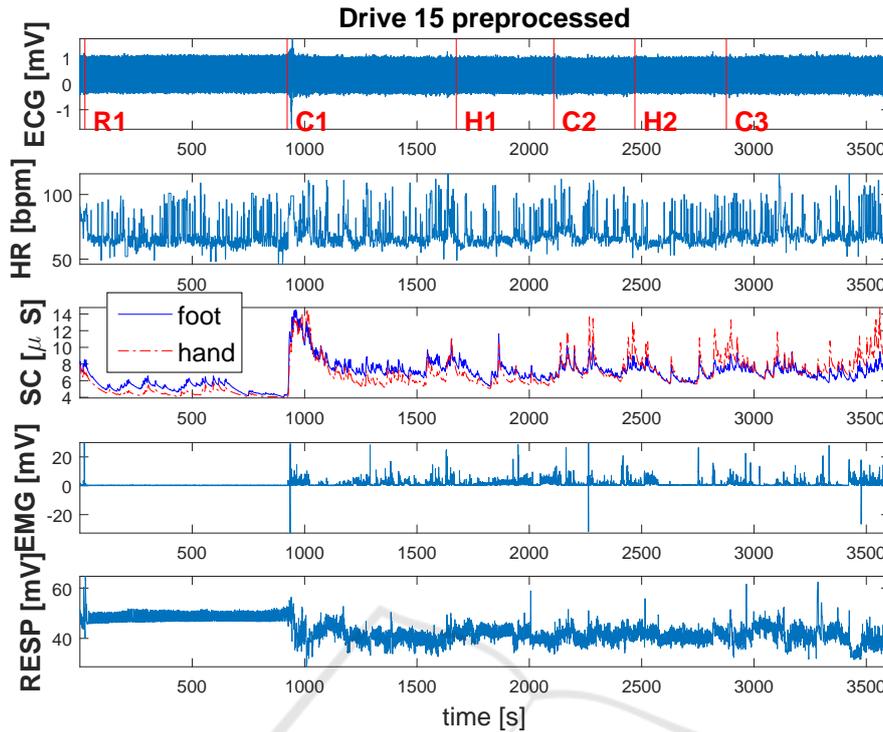


Figure 1: All physiological signals from Drive 15, preprocessed for artifact removal and split into 6 phases according to the marker signal.

with stress, corresponding to muscle tension. This can be observed by an increase in the signal energy.

A final physiological signal for detection of stress is the respiration, usually measured by a band that records chest expansion. This signal is highly coupled with HR by respiratory sinus arrhythmia, which decreases the HR while exhaling. The respiration signal can thus be used to remove respiratory influence on the ECG signal, allowing for more relevant HRV analysis in stress detection (Choi and Gutierrez-Osuna, 2010). The same applies for the SC signal, which increases while breathing out (Cacioppo et al., 2007, p. 239), making the respiration signal useful combined with electrodermal activity (Boucsein, 2012). Examples of respiration signal features for stress detection include ones related to breath size and its variability (e.g. the mean and standard deviation of the signal), and energy in different frequency bands (Yong Deng, 2013). Another example is the respiration rate (Wijsman et al., 2011).

4.1 Feature Calculation

Firstly, all signals were visually inspected for artifacts, e.g. unreasonably high heart rates (above 220 bpm) or sensor contact problems. Secondly, the preprocessed signals of each class were split into non-

overlapping time-windows of 60 seconds, each with a label $Y = -1$ or $Y = 1$ depending on the class of the time-window. For the RvsD classes, the number of samples n_s in each drive varied between 14 and 16 for class R and $37 \leq n_s \leq 52$ for class D . Similarly, for the HvsC classes, $13 \leq n_s \leq 17$ in class H and $22 \leq n_s \leq 36$ in class C . This means that the classes were imbalanced, which will be dealt with further on. The 14 selected features are specified in Table 2. The SC features originated from the hand electrodes; the foot SC signal was excluded due to it representing the same measure as the SC hand signal, which gives unwanted side effects on wrapper feature selection algorithms.

4.2 Normalization

To compensate for inter-individual differences (e.g. different resting heart rates), the initial rest period R_1 was used for normalizing each feature F to F_n according to

$$F_n = \frac{F - \mu_{R_n}}{\sigma_f}, \quad (1)$$

where σ_f represents the standard deviation of the feature across all users and periods and μ_{R_n} represents the mean of the feature during the last two time-windows of the initial rest period. Only the last two

Table 2: The features and their descriptions.

Feature	Description
Signal: HR [bpm]	
μ_{HR}	mean heart rate
$RMS_{IBIdiff}$	root mean square of successive differences of inter-beat intervals
LF_{HR}	sum of energy in low frequency (LF) band (0.04 – 0.15 Hz)
HF_{HR}	sum of energy in high frequency (HF) band (0.15 – 0.50 Hz)
$LFHF_{HR}$	ratio between energies in LF and HF bands
Signal: SC [mV] (foot and hand)	
μ_{SC}	mean skin conductance level
$\mu_{SC^{'+}}$	mean of positive derivative
$\mu_{ SC^{ }}$	mean of absolute derivative
$+ / SC^{'}$	proportion of positive samples in derivative
max_{SC}	number of local maxima
Signal: EMG [mV]	
RMS_{EMG}	root mean square of EMG
Signal: Resp [mV]	
$(\max - \mu)_{Resp}$	maximal respiration – mean of respiration (range)
F_{Resp}	respiration rate
σ_{Resp}	standard deviation of the respiration

time-windows were used since R_1 is also a class in the RvsD case. These two time-windows were subsequently deleted from the RvsD R class, to prevent their influence on the classifier accuracy. This means that after normalization, in the RvsD case class R contained $12 \leq n_s \leq 14$. The reason for dividing by the standard deviation across all features is to avoid bias of choosing features with great variance without involving any subject-specific data that could potentially lead to overlearning.

5 METHOD

Having defined a set of features, it is important to choose an optimal subset among them by different feature selection methods. This serves two purposes: training the most generalizable and accurate model, and getting a better understanding of the relationship between the physiological signals and the stress state of the subject. This subset (the feature space), needs to contain enough features to distinguish the classes, but limiting its size is important to avoid overfitting.

This can be done by univariate (filter) methods, that consider the features one by one, or by multivariate (wrapper) methods, that try different combinations of the features with the help of a classifier. The chosen methods are presented in Sections 5.2 and 5.3. For all feature selection methods, we define X as the features and Y as the labels.

5.1 Use Cases

By combining the two calibration methods described in Section 1 with the two previously explained class definitions (RvsD and HvsC), we obtain four use cases:

1. Rest versus driving, single-user
2. Rest versus driving, multi-user
3. Highway versus city, single-user
4. Highway versus city, multi-user

These four use cases were analyzed and compared, in order to provide a basis for an optimal feature and sensor choice for each of them. All the following methods have been applied to every use case.

5.2 Filter Feature Selection

This section presents all the filter feature selection methods used in this work. Their common element is that they test features individually, to get an idea of their predictive power of stress levels one by one (although some versions exist that are capable of analyzing feature combinations). For all filter methods, the single-user case means calculating the coefficients for each drive, then averaging across all drives. The multi-user case means putting the data from all drives together in a large vector, then calculating the coefficients.

Pearson's linear correlation coefficient r (Duda et al., 2000, p. 614) is a simple tool for studying the relevance of features. This can give a preliminary indication of the importance of a feature, but one must keep in mind that it only analyzes linear correlations.

Spearman's rank correlation ρ (Spearman, 1904) measures the statistical dependence between two variables by testing how well they can be related by a monotonic function. This has the advantage of being capable of detecting non-linear dependencies, as opposed to Pearson's linear correlation. Kendall's rank correlation coefficient (Kendall and Gibbons, 1990) was also tested, with identical results.

The **Fisher score** F_s (Arunasakthi et al., 2014) was

calculated for each feature. It is given by

$$F_s = \frac{(\mu_{(Y=-1)} - \mu_{(Y=1)})^2}{\sqrt{\sigma_{(Y=-1)}^2 + \sigma_{(Y=1)}^2}}, \quad (2)$$

where μ and σ correspond to the mean and the standard deviation of the feature over each class, respectively. Features having means that differ greatly across classes with low standard deviation will have high Fisher scores.

A widely used tool in classification problems is the **receiver operating characteristic** (ROC) (Hanley and Mcneil, 1982), which compares the number of correctly predicted positive samples among all positive samples (true positive rate, TPR), versus the number of falsely predicted positive samples among all positive samples (false positive rate, FPR). A ROC curve can be obtained by letting a feature predict the label when varying its threshold, followed by plotting FPR against TPR for each threshold. A feature with high predictive power will then maintain a high TPR with a low FPR. The area under the ROC curve (AUC) will thus increase, which is why it is an interesting analysis for feature selection. The numerical integration of the area under the curve was calculated by the trapezoid method.

5.3 Wrapper Feature Selection

Individually useless features can have a great predictive power when combined with other features in classification algorithms. Furthermore, a safe way of knowing that the feature subset is good, is letting the classifier itself choose it. Wrapper feature selection methods solve this problem by choosing feature combinations based upon their classification performance. This has of course the disadvantage of introducing a bias from the choice of classifier and its parameters, as well as increasing the risk of overlearning the model by adapting it too much to the data. For the wrapper feature selection, in the single-user case a 5-fold crossvalidation was performed, combined with bootstrap aggregating (Duda et al., 2000, p. 474) repeated 100 times (to reduce the variance in performance between the random crossvalidation subsets). In the multi-user case, leave-one-drive-out cross validation was used, by excluding one entire drive of one participant, and learning with the remaining ones. This gives the basis for a stress model that is generic (capable of classifying the state of new drivers that have not been used for training it). In multi-user, before the learning step, the minority class data was uniformly oversampled to achieve class balance, discouraging the model from always predicting only the majority class. Oversampling could not be done in the

single-user validation since both classes are not guaranteed to be represented in every bootstrap configuration.

5.3.1 The Naive Bayes Classifier

In this study, we use the naive Bayes (NB) classifier, a simple probabilistic classifier (Hastie et al., 2009, p. 210-211). Based upon the feature vector $\mathbf{X} = X_1, \dots, X_{n_f}$ (containing n_f features), it calculates the posterior probability $P(Y_c|\mathbf{X})$ of \mathbf{X} belonging to class Y_c (among a total of n_c classes) using Bayes' theorem:

$$P(Y_c|\mathbf{X}) = \frac{P(Y_c)P(\mathbf{X}|Y_c)}{P(\mathbf{X})}. \quad (3)$$

The prior probability $P(Y_c)$ is simply the frequency of class Y_c . The evidence $P(\mathbf{X})$ is the frequency of the feature, which is irrelevant for the classification problem. The NB classifier assumes conditional independence of all features \mathbf{X} in class c , i.e. that no correlations exist between them. The likelihood $P(\mathbf{X})$ can thus be written as

$$P(\mathbf{X}|Y_c) = \prod_{f=1}^{n_f} P(X_f|Y_c). \quad (4)$$

Assuming a normal distribution of the data (Gaussian naive Bayes), the learning step consists of calculating the mean $\mu_{f,c}$ and the standard deviation $\sigma_{f,c}$ of each feature f over each class c . The likelihood of a new observation \mathbf{X} belonging to class Y_c is then given by

$$P(X_f|Y_c) = \frac{1}{\sqrt{2\pi\sigma_{f,c}^2}} e^{-\frac{(X_f - \mu_{f,c})^2}{2\sigma_{f,c}^2}}. \quad (5)$$

The class of \mathbf{X} is finally predicted as the one with the highest posterior probability:

$$\hat{Y} = \arg \max_{Y_c} P(Y_c|\mathbf{X}). \quad (6)$$

The motive behind choosing the naive Bayes classifier is that it is parameterless (unlike e.g. support vector machines (SVM), (Hastie et al., 2009, p. 417-419)). An SVM requires choosing an appropriate kernel and tuning a parameter, which will not necessarily be the same for all our use cases.

5.3.2 Performance Measure

To measure the classifier performance, we define the balanced accuracy

$$a_b = \frac{\text{TPR} + \text{TNR}}{2}, \quad (7)$$

TNR being the true negative rate, the amount of correctly predicted negatives among all negative samples. The balanced accuracy punishes misclassification of minority class samples more heavily, compensating for the fact that the classes are not represented by the same number of samples. Upon a_b , the margin of error at 95 % is defined:

$$m = 1.96 \sqrt{\frac{a_b(1-a_b)}{n_s}}, \quad (8)$$

where n_s represents the total number of samples used in the cross-validated prediction.

5.3.3 Exhaustive Feature Selection

The absolutely safest way of choosing an optimal feature space is to test the classification performance of all possible subsets, i.e. exhaustive feature selection. This quickly becomes very computationally expensive. To reduce this problem, an exhaustive feature selection was performed within the features of each sensor, giving an optimal subset of features from every sensor signal. To decide whether adding an additional feature gave a significant improvement or not, Student's paired t-test (Kreyszig, 1970, p. 206) was performed on all cross-validated performances, with a significance threshold set at 0.05. Similarly, Student's paired t-test was performed to decide if each performance was significantly greater than pure guessing ($a_b = 50\%$), denoted t_{50} , also with a significance threshold set at 0.05.

5.3.4 Sensor Selection

When an optimal subset for each individual sensor had been defined, the respective subsets were combined. This resulted in six sensor pairs, four sensor triples and finally one combination where all four sensors were represented. The combination with the best classification performance was then chosen for each use case. t_{50} was also calculated for each sensor combination, to determine if its performance was superior to random guessing.

6 RESULTS AND DISCUSSION

The results of the previously mentioned feature selection methods are presented and discussed in this section. Table 3 summarizes the best 5 features according to the filter feature selection methods. For each method and use case, the features have been given a rank (descending order through the 14 tested features), depending on their filter feature selection

score. The mean of all ranks μ_{rank} has then been calculated, to give a notion of the combined score for each feature across all the methods. Table 4 presents the optimal combination of features extracted from each sensor (exhaustively selected). The "Sensors" row then specifies the optimal sensor combination. Results upon validation data are presented for each optimal feature combination, using the balanced accuracy a_b . Across the two tables, seven features are frequently represented: \max_{SC} , μ_{HR} , μ_{SC} , $\mu_{|SC'|}$, $+ / SC'$, $(\max - \mu)_{Resp}$, and σ_{Resp} . To a lesser extent, five other features can also be found: RMS_{EMG} , F_{Resp} , $\mu_{SC'+}$, LF_{HR} , and HF_{HR} . In terms of sensor choice, the HR sensor is consistently chosen across all cases, often with support of SC and/or respiration respiration measures. The EMG sensor is chosen only in one of the cases. As in (Akbas, 2011) and (Queyam, 2013), the mean heart rate and the mean SC level prove themselves relevant. Like in (Healey and Picard, 2005) and (Yong Deng, 2013), μ_{SC} is among the top choices. σ_{Resp} is not present in previous studies on the same database, which primarily favor the respiration rate.

Concerning the classification performances, RvsD is a quite easy task, even in multi-user. Using only the respiration signal, reasonable accuracy is reached. HvsC is naturally more difficult, reaching significant accuracy in the single-user case, while the multi-user case is just slightly above random guessing for some sensors. Compared to previous studies (e.g. 94.7 % in (Healey and Picard, 2005)), the classification performances are quite low, at least for the HvsC. However in terms of calibration, cross-validation method and signal segmentation with respect to the experimental phases, this study corresponds to a more realistic application.

To further validate the results, the same study with other classifier algorithms should be done. No complete exhaustive feature selection is performed, since this is firstly done within each sensor. This means that not all feature combinations are considered, and feature combinations that might improve accuracy could be excluded. It would however be extremely time-consuming to try all feature combinations, which is why we perform a subselection within each sensor firstly. Furthermore, when selecting sensors it is important to point out that an EMG sensor is complicated to equip and can be quite invasive, which is also true for the respiration sensor to a certain extent. It is mainly the HR and SC signals that can be acquired by simple wearable sensors with the current technology, which is important to point out when selecting them.

Table 3: Top 5 ranked features for each use case, according to the filter methods.

Feature	r	ρ	F_s	AUC	μ_{rank}
Rest vs. driving, single-user					
μ_{SC}	2	2	2	1	1.75
$+/SC'$	3	3	3	2	2.75
\max_{SC}	1	1	1	11	3.5
$\mu_{ SC' }$	5	4	6	3	4.5
μ_{HR}	4	6	4	6	5
Rest vs. driving, multi-user					
\max_{SC}	1	1	1	1	1
μ_{SC}	3	2	3	2	2.5
$+/SC'$	2	3	2	3	2.5
μ_{HR}	4	5	4	5	4.5
$\mu_{ SC' }$	5	4	5	4	4.5
Highway vs. city, single-user					
\max_{SC}	1	2	1	2	1.5
σ_{Resp}	2	1	3	1	1.75
μ_{SC}	3	4	2	3	3
$\mu_{ SC' }$	5	3	5	4	4.25
$+/SC'$	4	6	4	6	5
Highway vs. city, multi-user					
\max_{SC}	1	2	1	2	1.5
σ_{Resp}	2	1	3	1	1.75
$\mu_{ SC' }$	4	3	4	3	3.5
$+/SC'$	3	5	2	5	3.75
$(\max - \mu)_{Resp}$	5	4	5	4	4.5

7 CONCLUSIONS

In terms of classification, learning one model per user yields better accuracy than creating a universal multi-user model. Moreover, classifying rest from activity is easier than classifying a less stressful task from a more stressful one. Independently of the classification problem (rest from activity or low stress from high stress) and independently of the calibration method, seven features have been found to be robust across both filter and wrapper methods: \max_{SC} , μ_{HR} , μ_{SC} , $\mu_{|SC'|}$, $+/SC'$, $(\max - \mu)_{Resp}$, and σ_{Resp} . The filter feature selection used in this study has given a good preliminary idea of the usefulness of each feature, but to deal with feature combinations wrapper methods are necessary.

A problem with the MIT Stress Recognition in Automobile Drivers Database is that it consists solely of one type of stress. For a robust real-time algorithm to work in daily life, one needs to identify stress characteristics from several different stress types. This is the purpose of an experimental database currently in development, where laboratory stressors correspond-

Table 4: Exhaustive feature selection and sensor selection results.

Signal	Optimal content	$a_b \pm m$ [%]	t_{50}
Rest vs. driving, single-user			
HR	μ_{HR} , LF_{HR} , HF_{HR}	82.3 ± 3.3	1
SC	μ_{SC} , $\mu_{SC'+}$, $+/SC'$	93.2 ± 2.2	1
EMG	RMS_{EMG}	87.5 ± 2.8	1
Resp	$(\max - \mu)_{Resp}$, F_{Resp} , σ_{Resp}	89.3 ± 2.7	1
Sensors	$HR + SC$	94.6 ± 1.9	1
Rest vs. driving, multi-user			
HR	μ_{HR}	76.0 ± 3.6	1
SC	\max_{SC}	83.6 ± 3.2	1
EMG	RMS_{EMG}	66.6 ± 4.0	1
Resp	$(\max - \mu)_{Resp}$, F_{Resp} , σ_{Resp}	85.3 ± 3.0	1
Sensors	$HR + SC + Resp$	87.3 ± 2.8	1
Highway vs. city, single-user			
HR	μ_{HR} , LF_{HR}	64.8 ± 4.7	1
SC	μ_{SC} , $\mu_{SC'+}$, $\mu_{ SC' }$, \max_{SC}	74.9 ± 4.3	1
EMG	RMS_{EMG}	59.4 ± 4.8	1
Resp	$(\max - \mu)_{Resp}$, F_{Resp} , σ_{Resp}	71.2 ± 4.4	1
Sensors	$HR + SC + Resp$	78.1 ± 4.1	1
Highway vs. city, multi-user			
HR	μ_{HR}	60.1 ± 4.7	1
SC	μ_{SC} , $\mu_{ SC' }$, \max_{SC}	65.0 ± 4.6	1
EMG	RMS_{EMG}	57.7 ± 4.7	1
Resp	$(\max - \mu)_{Resp}$, F_{Resp} , σ_{Resp}	71.8 ± 4.3	1
Sensors	$HR + EMG + Resp$	72.1 ± 4.3	1

ing to different stress types are applied to subjects equipped with a similar sensor configuration. Additionally, an experiment is planned where the subjects are equipped with wearable sensors every day for a week, allowing an analysis of physiological reactions to daily events, including transport and driving. Future work includes acquiring and analyzing this data, for further validation of the most relevant sensors and features in stress detection.

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REFERENCES

- Akbas, A. (2011). Evaluation of the Physiological Data Indicating the Dynamic Stress Level of Drivers. *Scientific Research and Essays*, 6(2):430 – 439.
- Arunasakthi, K., KamatchiPriya, L., and Askerunisa, A. (2014). Fisher Score Dimensionality Reduction for Svm Classification. In *International Conference on Innovations in Engineering and Technology (ICIET14)*, pages 1900–1904. International Journal of Innovative Research in Science, Engineering and Technology.
- Boucsein, W. (2012). *Electrodermal Activity*. The Springer series in behavioral psychophysiology and medicine. Springer US.
- Bořil, H., Boyraz, P., and Hansen, J. H. (2009). Towards Multi-Modal Drivers Stress Detection. In *4th Biennial Workshop on DSP for In-Vehicle Systems and Safety, Dallas, TX, USA*.
- Cacioppo, J. T., Tassinary, L. G., and Berntson, G., editors (2007). *Handbook of Psychophysiology*. Cambridge University Press, third edition. Cambridge Books Online.
- Choi, J. and Gutierrez-Osuna, R. (2010). Estimating Mental Stress Using a Wearable Cardio-respiratory Sensor. In *Proceedings of IEEE Sensors*, pages 150–154. IEEE.
- Duda, R. O., Hart, P. E., and Stork, D. G. (2000). *Pattern Classification*. Wiley-Interscience, second edition.
- Gao, H., Yuce, A., and Thiran, J.-P. (2014). Detecting Emotional Stress from Facial Expressions for Driving Safety. In *Image Processing (ICIP), 2014 IEEE International Conference on*, pages 5961–5965.
- Hanley, J. A. and Mcneil, B. J. (1982). The Meaning and Use of the Area Under a Receiver Operating Characteristic (ROC) Curve. *Radiology*, 143:29–36.
- Hastie, T., Tibshirani, R., and Friedman, J. (2009). *The Elements of Statistical Learning*. Springer, second edition.
- Healey, J. and Picard, R. (2000). SmartCar: Detecting Driver Stress. In *Pattern Recognition, 2000. Proceedings. 15th International Conference on*, volume 4, pages 218–221.
- Healey, J. and Picard, R. W. (2008). Stress Recognition in Automobile Drivers (drivedb). Available at <http://physionet.org/cgi-bin/atm/ATM>.
- Healey, J. A. and Picard, R. W. (2005). Detecting Stress During Real-World Driving Tasks Using Physiological Sensors. *Intelligent Transportation Systems, IEEE Transactions on*, 6(2):156–166.
- Hennessy, D. A. and Wiesenthal, D. L. (1999). Traffic Congestion, Driver Stress, and Driver Aggression. *Aggressive Behavior*, 25(6):409–423.
- Hernandez, J., McDuff, D., Benavides, X., Amores, J., Maes, P., and Picard, R. (2014). AutoEmotive: Bringing Empathy to the Driving Experience to Manage Stress. In *Proceedings of the 2014 Companion Publication on Designing Interactive Systems, DIS Companion '14*, pages 53–56, New York, NY, USA. ACM.
- Kappeler-Setz, C., Arnrich, B., Schumm, J., La Marca, R., Tröster, G., and Ehlert, U. (2010). Discriminating Stress From Cognitive Load Using a Wearable EDA Device. *IEEE Transactions on Information Technology in Biomedicine*, 14(2):410–417.
- Kendall, M. and Gibbons, J. (1990). *Rank Correlation Methods*. A Charles Griffin Book. E. Arnold.
- Kreyszig, E. (1970). *Introductory Mathematical Statistics: Principles and Methods*. Wiley.
- Lundberg, U., Kadefors, R., Melin, B., Palmerud, G., Hassmén, P., Engström, M., and Elfsberg Dohns, I. (1994). Psychophysiological Stress and EMG Activity of the Trapezius Muscle. *International Journal of Behavioral Medicine*, 1(4):354–370.
- Palinko, O., Kun, A. L., Shyrokov, A., and Heeman, P. (2010). Estimating Cognitive Load Using Remote Eye Tracking in a Driving Simulator. In *Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications, ETRA '10*, pages 141–144, New York, NY, USA. ACM.
- Queyam, A. B. (2013). A Novel Method of Stress Detection using Physiological Measurements of Automobile Drivers. Master's thesis, Thapar University.
- Rigas, G., Goletsis, Y., and Fotiadis, D. (2012). Real-Time Driver's Stress Event Detection. *Intelligent Transportation Systems, IEEE Transactions on*, 13(1):221–234.
- Singh, M. and Queyam, A. B. (2013). Stress Detection in Automobile Drivers using Physiological Parameters: A Review. *International Journal of Engineering Education*, 5(2):1–5.
- Spearman, C. (1904). The Proof and Measurement of Association Between Two Things. *American Journal of Psychology*, 15:88–103.
- Sun, F., Kuo, C., Cheng, H., Buthpitiya, S., Collins, P., and Griss, M. L. (2010). Activity-Aware Mental Stress Detection Using Physiological Sensors. In *Mobile Computing, Applications, and Services - Second International ICST Conference, MobiCASE 2010, Santa Clara, CA, USA, October 25-28, 2010, Revised Selected Papers*, pages 211–230.
- Wijisman, J., Grundlehner, B., Liu, H., Hermens, H., and Penders, J. (2011). Towards Mental Stress Detection Using Wearable Physiological Sensors. In *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, pages 1798–1801.
- Yong Deng, Zhonghai Wu, C.-H. C. Q. Z. D. F. H. (2013). Sensor Feature Selection and Combination for Stress Identification Using Combinatorial Fusion. *International Journal of Advanced Robotic Systems*, 10.