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|-----------------------------|--|
| Title | MixedEmotions: An open-source toolbox for multi-modal emotion analysis |
| Author(s) | Buitelaar, Paul; Wood, Ian D.; Negi, Sapna; Arcan, Mihael; McCrae, John P.; Abele, Andrejs; Robin, Cécile; Andryushechkin, Vladimir; Ziad, Housam; Sagha, Hesam; Schmitt, Maximilian; Schuller, Björn W.; Sánchez-Rada, J. Fernando; Iglesias, Carlos A.; Navarro, Carlos; Giefer, Andreas; Heise, Nicolaus; Masucci, Vincenzo; Danza, Francesco A.; Caterino, Ciro; Smrz, Pavel; Hradíš, Michal; Povolný, Filip; Klimeš, Marek; Matjka, Pavel; Tummarello, Giovanni |
| Publication Date | 2018-01-25 |
| Publication Information | Buitelaar, P. and Wood, I. D. and Negi, S. and Arcan, M. and McCrae, J. P. and Abele, A. and Robin, C. and Andryushechkin, V. and Ziad, H. and Sagha, H. and Schmitt, M. and Schuller, B. W. and Sanchez, J. F. and Iglesias, C. A. and Navarro, C. and Giefer, A. and Heise, N. and Masucci, V. and Danza, F. A. and Caterino, C. and Smrz, P. and Hradis, M. and Povolny, F. and Klimes, M. and Matejka, P. and Tummarello, G. (2018). MixedEmotions: An Open-Source Toolbox for Multimodal Emotion Analysis. <i>IEEE Transactions on Multimedia</i> , 20(9), 2454-2465. doi: 10.1109/TMM.2018.2798287 |
| Publisher | IEEE |
| Link to publisher's version | https://dx.doi.org/10.1109/TMM.2018.2798287 |
| Item record | http://hdl.handle.net/10379/14653 |
| DOI | http://dx.doi.org/10.1109/TMM.2018.2798287 |

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MixedEmotions: An Open-Source Toolbox for Multi-Modal Emotion Analysis

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Abstract—Recently, there is an increasing tendency to embed functionalities for recognizing emotions from user generated media content in automated systems such as call-centre operations, recommendations and assistive technologies, providing richer and more informative user and content profiles. However, to date, adding these functionalities was a tedious, costly, and time consuming effort, requiring identification and integration of diverse tools with diverse interfaces as required by the use case at hand. The MixedEmotions Toolbox leverages the need for such functionalities by providing tools for text, audio, video, and linked data processing within an easily integrable plug-and-play platform. These functionalities include: (i) for text processing: emotion and sentiment recognition, (ii) for audio processing: emotion, age, and gender recognition, (iii) for video processing: face detection and tracking, emotion recognition, facial landmark localization, head pose estimation, face alignment, and body pose estimation, and (iv) for linked data: knowledge graph integration. Moreover, the MixedEmotions Toolbox is open-source and free. In this article, we present this toolbox in the context of the existing landscape, and provide a range of detailed benchmarks on standard test-beds showing its state-of-the-art performance. Furthermore, three real-world use-cases show its effectiveness, namely emotion-driven smart TV, call center monitoring, and brand reputation analysis.

Index Terms—emotion analysis, open source toolbox, affective computing, linked data, audio processing, text processing, video processing

I. MOTIVATION & INTRODUCTION

ANY Media content (e.g., social media, TV/Radio program) contains a vast amount of information which can be harvested for various analysis from a content perspective (e.g., reputation analysis [1], content emotion analysis [2]) and a content-authors perspective (e.g., user profiling and recommendation [3], [4], user community analysis [5], [6]).

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This paper has supplementary downloadable material available at <http://ieeexplore.ieee.org/>, provided by the author. The material includes ‘entities.png’, ‘ex-linked-data.pdf’, ‘ex-social-tv.png’, ‘ex-call-center.png’, and ‘ex-brand-reputation.png’. Contact paul.buitelaar@insight-centre.org for further questions about this work.

Nevertheless, as part of this information, the emotional aspects of the media content has not received its well-deserved attention and its utility of those aspects have not yet been well-exploited in real-world or commercial scenarios. Emotions are important part of human life as they enhance communication and understanding between people. Similarly, incorporating emotion-related information into multimedia content and multimedia analysis could enhance usability and user-adaptability. Although some research advances have been made in this direction (such as: emotion analysis of users’ audio or video for enriching users’ profiles for media recommendation [3], [7], [4], affect prediction from movies [8], or speech [9]), they have not gone further than research, and reproduction of such algorithms is time consuming and fault-prone.

The MixedEmotions Toolbox¹ introduced herein fills this gap by providing a plug-and-play and ready-to-use set of emotion recognition modules that can be used in isolation or in combination through predefined or configurable workflows. It provides a unified solution for large-scale emotion analysis on heterogeneous, multilingual, text, speech, video, and social media data streams, leveraging open access and proprietary data sources including modules for collection of social media data, and exploiting social context by leveraging social network graphs. It also includes entity linking and knowledge graph technologies for semantic-level emotion information aggregation and integration. Available free tools have been adapted and included in the platform alongside tools developed by the authors of this paper.

This paper describes the current version of the MixedEmotions Toolbox, including its underlying architecture, the modules it comprises and their capabilities, and applications of the platform in three representative multimedia-related use cases: Social TV, Brand Reputation Management, and Call Center Operations.

Before describing the toolbox in detail, we describe what *emotion* actually is and how it is represented and provide a

¹MixedEmotions Toolbox is the outcome of the European Project MixedEmotions (<https://mixedemotions-project.eu/>). Note that it is not about the ‘co-occurrence of different emotions’ (as the psychological term ‘mixed emotions’), but about the ‘emotions from mixed modalities’.

quick review of existing emotion analysis platforms as well as an overview of requirements for emotion analysis on big-data.

A. What is Emotion?

One of the most complete and accepted definitions of emotion is proposed by Scherer [10] through a component process model, in which an emotion is a synchronization of different cognitive and physiological components in response to a stimulus event. The expression of emotions through facial and vocal changes is originated from the ‘somatic nervous system’ component. Moreover, emotions and preferences (as stable emotions with low behavioural impacts) can be conveyed through verbal or written *content*, such as product reviews, opinions, and suggestions. Therefore, analysing the facial and vocal changes as well as verbal and written content provides clues for automatic emotion recognition.

B. Quick overview of emotion representations used

Various representation schemes for emotions have been proposed, each based on particular criteria. Ekman’s *six basic emotions* (Anger, Fear, Surprise, Happiness, Disgust, Sadness) are based on the universality of those emotions [11]; Plutchik’s *wheel of emotion* is further based on contrast and closeness of emotions [12]; Russel’s *Circumplex model* is constructed to capture the core affect in a two dimensional (Arousal and Valence) model [13], [14]; Osgood identified three primary dimensions of emotion expression (Pleasure, Arousal, Dominance) [15]; and more recently, Fontaine et al. identified a fourth dimension (unpredictability) [16]. Arousal reflects the level of energy in the emotion (e.g., pleased vs. ecstatic); valence reflects the hedonic tone (e.g., pleasant vs. unpleasant); dominance represents the sense of control or dominant nature of the emotion (e.g., fear vs. anger); and unpredictability refers to the appraisal of expectedness or familiarity.

In the MixedEmotions Toolbox, the preferred emotion representation model is the four dimensional model, combined with emotion intensity as a fifth dimension and a level of confidence in the measurement. However, due to limitations in available gold standard data and error-prone human ability to map perceived emotions into these dimensions, some modules in the MixedEmotions Toolbox represent emotions as a subset of these dimensions. For emotion representation in audio and video processing, we chose a two (arousal and valence) or three (+ dominance) dimensional emotion model. The choice of the dimensional model is due (among others) to: (i) it can be mapped not only to the six basic emotions but to a myriad of emotion categories, (ii) emotions which resemble each other are located in the vicinity of each other, (iii) it is easier to define continuous values as the output of machine learning systems (such as neural networks), and (iv) it is easier to handle the decision fusion of different subsystems in the continuous domain. In the analysis of text, there were previously no substantial resources annotated with a dimensional emotion model; however, resources and tools that utilize Ekman’s six basic emotions were available. In addition, there are many resources available for “sentiment analysis”, which is essentially just the Valence dimension. For this reason, several

toolbox modules for text analysis utilize these representation schemes, and functionality is provided for translating to and from a dimensional representation. New data annotated with a four dimensional model is provided alongside models for detecting emotion with this scheme utilising the new data.

C. Existing emotion analysis platforms

Some web services for emotion analysis from textual contents, facial expressions, and speech already exist. Table I summarizes some known services along with their characteristics. As can be seen in the table, all the services are for the analysis of only one modality such as facial, textual, or speech. Moreover, most of the services are not free and not open-source. The MixedEmotions Toolbox overcomes these limitations by providing multi-modal, open-source, free, and user-friendly emotion analyzers.

D. Emotion Analysis in Big Data and Pre-requisites

To deploy a multifaceted emotion analyzer for big-data, the seven “Vs” of big data (Volume, Velocity, Variety, Variability, Veracity, Visualization, and Value) should be addressed. Among them, Variety encompasses multimodality (audio, video, text) and multilinguality/multiculturalism, and Veracity emerges from subjectivity of assessments (annotations). These aspects have been addressed for: (i) the textual modality by: automatic translation [17], defining multilingual WordNet Grid [18], and (ii) for the audio modality by: analyzing within or between language family emotion recognition [19], feature transfer learning between languages [20], model transfer learning [21], language identification [22], audio denoising [23], and decision aggregation through cooperative speaker models [24]. Regarding the Volume and Velocity, there is a need for fast computation. This has been investigated using End-to-End approaches for speech emotion analysis [25], fast GPU processing of audio and video processing [26], and crowdsourcing and a semi-supervised active learning approach for automatically labeling large amounts of data [27], [28]. Some of these aspects have been deployed within the MixedEmotions Toolbox. Further, the MixedEmotions Toolbox can be easily deployed on one or more machines for distributed analysis and fast processing of large amount of data. A Visualization module is also included in the toolbox (Section III-D). Moreover, to investigate the Value of this MixedEmotions Toolbox, we designed three case studies on multimedia emotion processing which will be discussed in Section IV.

II. ARCHITECTURE OVERVIEW

The MixedEmotions Toolbox follows a microservice architecture in which the modules in the toolbox are independent of each other, so users need only the modules required for his/her analysis and can skip the others. The modules are containerized using Docker², and therefore can be deployed without dependency restrictions, with the only requirement being a Docker server. Docker servers exist for all major operating systems, can be installed on small computers as well

²www.docker.com

TABLE I
A SHORT LIST OF AVAILABLE EMOTION ANALYZER SERVICES FOR T(EXTUAL), F(ACIAL), AND S(PEECH) CONTENTS.

| Service | Modality | Open Source | Free |
|--|----------|-------------|-----------------------------------|
| IBM Watson AlchemyLanguage (www.ibm.com/watson), Bitext (www.bitext.com) | T | No | No |
| MoodPatrol (market.mashape.com/soulhackerslabs/) | T | No | No |
| Synesketch (krcadinac.com/synesketch) | T | Yes | Yes |
| Microsoft Cognitive Services (www.microsoft.com/cognitive-services) | F | No | No |
| IMOTIONS (www.imotions.com) | F | No | No |
| Affectiva Emotion API (www.affectiva.com) | F | No | Free/Enterprise Editions |
| EmoVu (www.emovu.com), CrowdEmotions (www.crowdemotion.co.uk) | F | No | ? |
| Nviso (www.nviso.ch/technology.html), SkyBiometry (www.skybiometry.com) | F | No | Limited/Non-Free Editions |
| audEERING SensAI (www.audeering.com/technology/sensai/) | S | Yes | Free Research Edition (openSMILE) |
| Good Vibrations (www.good-vibrations.nl) | S | No | No |
| Vokaturi (www.vokaturi.com/) | S | No | Limited/Enterprise Editions |

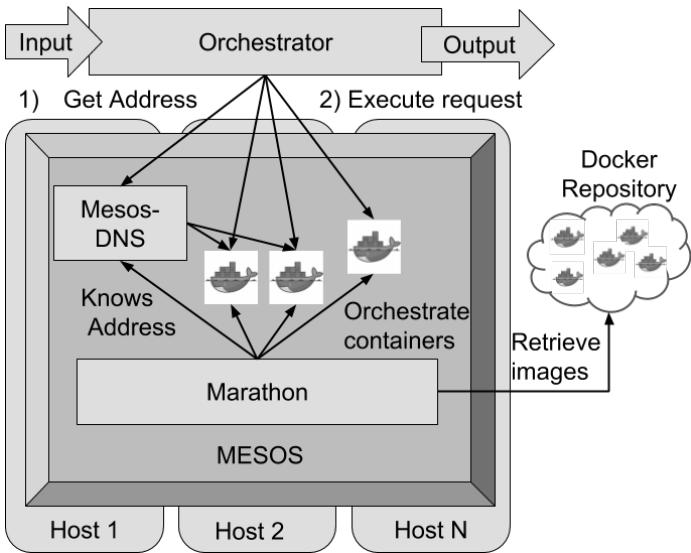


Fig. 1. Orchestrator within the MixedEmotions Toolbox.

as in extensible cloud environments. As well as individual modules, users can also benefit from an orchestrator in the toolbox to enable big data operations sustained on horizontal scalability (using more machines). This orchestrator provides users an easy starting point to build applications as needed. In a nutshell, the orchestrator is an ETL³ pipeline [29] adapted to the structure of the MixedEmotions, thus, it is suited to work with Docker containers deployed in Mesos⁴(Fig. 1), as well as external services as long as they have a REST API⁵. It is fully configurable with plain text configuration files, so a user does not need to have programming skills.

Note that Docker Servers and Mesos Services can be deployed on multiple platforms, including, Linux, OS X, Windows and Windows Server, and making the MixedEmotions Toolbox platform independent.

³Extract, Transform, Load

⁴mesos.apache.org: The Mesos kernel runs on every machine and provides applications with API's for resource management and scheduling across entire datacenter and cloud environments.

⁵REST = Representational State Transfer, API=Application Programming Interface. This is a simple and widely used standard for providing services over the internet.

Where to find the MixedEmotions Toolbox

The MixedEmotions platform is available online for demonstration and testing⁶. Open source and free for research purposes modules are located on GitHub⁷ (source code and documentation), and ready-to-use modules can be found in the MixedEmotions docker repository⁸.

III. OVERVIEW OF MAIN FUNCTIONALITIES

In this section, we describe the modules in the MixedEmotions Toolbox for text, audio, and video processing with the focus of emotion recognition.

A. Text Processing

The toolbox includes the following modules for text processing: (1) several modules that implement recognition of affect expressed in text, (2) a module for the recognition of suggestions expressed in text, and (3) modules for semantic processing of text. While sentiment analysis (the recognition of positive/negative sentiment often directed at a particular entity) is an established field with many standard data sets and well developed methodologies (e.g., [30]), the recognition of more nuanced affect has received less attention, and in particular, there are very few gold standard annotated resources. This is also true for analysis of sentiment and emotion from many languages. To address this lack, two new resources for emotion detection from text were developed: (4a) a collection of tweets annotated with four emotion dimensions, and (4b) translations of WordNet into all official European languages, enabling the application of WordNet-based affective lexical resources (e.g., WordNet-Affect [31] and Senti-WordNet [32]) in those languages. Details of these modules and resources are as follows.

1) *Sentiment and Emotion Recognition*: Models for sentiment and emotion recognition from text across several languages and for general text and social media domains are included in the platform (see Tables II and III).

Several free and/or open source sentiment analysis tools are included in the toolbox. In addition, two Long-Short Term Memory (LSTM) [33] deep learning models trained on

⁶<http://mixedemotions.insight-centre.org/>

⁷<https://github.com/MixedEmotions>

⁸<https://hub.docker.com/r/mixedemotions/>

movie reviews [34] and tweets [35] are provided (see Table II). Evaluation of the English language sentiment models was performed on test tweets from the SemEval2015 task 10B [36] for tweet models, and movie reviews from [37] for general text models. F1 scores from the cross-validation analysis of the training data are also provided where appropriate.

The toolbox includes models for emotion detection from text for two emotion representation schemes: Ekman's six emotion categories [11] and the 4-dimensional Valence/Arousal/Dominance/Surprise representation scheme [16] (see Table III). These models fall into two broad categories: unsupervised lexicon based models, provided primarily as baseline systems, and supervised models trained on publicly available annotated data sets. The lexicon based models count word occurrences, summing associated emotions. Models built with WordNet-Affect [31] for Ekman emotions and Affective Norms for English Words (ANEW) [43], [44] for VAD are also provided. Two supervised Ekman models are included: one trained on tweet data utilising emotion hash tags as noisy emotion labels [45] and another from the recent WASSA shared task on emotion recognition [46], [47]. A final model trained on new VADS annotated data (see Section III-A4a) is also provided. F_1 and R^2 scores from the cross-validation analysis of the training data are provided where appropriate.

2) *Suggestion Mining*: Alongside requirements for the detection of sentiment and emotions in an opinionated text, another useful service which has been developed in the MixedEmotions Toolbox is the identification of suggestions and advice that may have been made in those texts. This will allow users and service providers to make more valuable decisions based on richer inferences on data (e.g., a brand reputation can be affected by positive and negative suggestions from the users alongside with their expressed sentiments).

Suggestion mining refers to the task of detection of such suggestions (advice, tips, recommendations, etc.) in the text obtained from social media. An example of suggestion in tweets can be: “*Dear Microsoft, release a new zune with your wp7 launch on the 11th. It would be smart*”. Since suggestion mining is a very recent area of research, our contribution also covers the creation of benchmark datasets to facilitate the development and evaluation of suggestion mining methods [49]. Currently, this module is only available for the English language.

The module utilises a Long Short Term Memory (LSTM) Neural Network to classify texts as suggestion or not suggestion. It is trained on suggestion mining datasets developed in-house, using crowdsourced annotations of hotel and electronics reviews [49]. This classifier yields a F_1 score of 0.64 and 0.67 over 10-fold cross-validation for hotel and electronics datasets respectively.

3) *Semantic Analysis of Text*: The toolbox includes modules for entity recognition in Spanish and English, both built on DBpedia⁹ [50]. The English module issues queries to a Lucene¹⁰ database containing all matching Wikipedia URIs,

⁹DBpedia is a crowd-sourced community effort to extract structured information from Wikipedia and make this information available on the Web.

¹⁰Apache Lucene is an open-source search software: <https://lucene.apache.org/>

and entities are selected according to the score from the Lucene index. The DBpedia URI, the entity and its type are returned by the module.

The Spanish Entity recognition module is created using entities from DBpedia and their inlink count, which is the number of other entities related to it. Then, an *entities dictionary* is created using all the entities above a certain threshold. Given a text, the module will then extract all the phrases that can be found in the entities dictionary.

4) *New Resources for Affective Analysis of Text*:

a) *Emotion annotated text data (standard and new)*:

There exists a limited number of publicly available emotion annotated text resources; these include: two thousand news headlines annotated with Ekman's six emotions [51], and several dimensionally annotated corpora: Affective Norms for English Texts [52] (a collection of 120 generic texts with VAD annotations), a collection of 2895 Facebook posts annotated by two annotators with Valence and Arousal dimensions [53], and the recent EMOBANK [54] (a collection of ten thousand texts from diverse sources but not including tweets). Moreover, Yu et al. [55] presented a collection of 2009 Chinese sentences from various online texts annotated with Valence and Arousal.

As a step towards addressing this limitation, we collected two new annotated tweet corpora: one containing 2019 generic tweets annotated with *Valence*, *Arousal*, *Dominance*, and *Surprise* (with annotator agreement of Krippendorffs' Alpha .42) [56], and another containing 360 tweets containing expressive emoji annotated with Ekman's six emotions [57] (with annotator agreement of Krippendorffs' Alpha .33).

b) *Polylingual WordNet*:

The Princeton WordNet [58] is one of the most important resources for natural language processing, but is only available for English. Although it has been translated using the *expand* approach to many other languages [59], [60], [61], most of the WordNet resources resulting from these efforts have fewer synsets than the Princeton WordNet. Since manual translation and evaluation of WordNets is a very time consuming and expensive process, we apply Statistical Machine Translation (SMT)¹¹ to automatically translate WordNet entries. The biggest challenge in translating WordNets with an SMT system lies in the need to translate all senses of a word including low frequency senses. While an SMT system can only return the most frequent translation when given a term by itself, it has been observed that it provides strong word sense disambiguation when the word is given in a disambiguated context [17]. Therefore, we leverage existing translations of WordNet in other languages to identify contextual information for WordNet senses from a large set of generic parallel corpora. We used an approach to select the most relevant sentences from a parallel corpus based on the overlap with existing translations of WordNet in as many pivot languages as possible. The goal is to identify sentences that share the same semantic information with respect to the synset of the WordNet entry that we want to translate. This approach allows us to provide a large multilingual WordNet in 23 different European languages, which we call Polylingual

¹¹The SMT models also exist as a MixedEmotions' module.

TABLE II
MODELS FOR SENTIMENT DETECTION FROM TEXT.
EVALUATION DATA: SEMEVAL2015 TASK 10B [36] (TWEET SENTIMENT), MOVIE REVIEWS FROM [37] (TEXT SENTIMENT)

| Affect Representation | Lang | Domain | Algorithm | Train CV F_1 | Test F_1 | Reference |
|--------------------------------|-------|--------|-------------------------|----------------|------------|----------------------|
| Sentiment (+,n,-) | EN | Text | LSTM | — | .76 | [33] trained on [34] |
| Sentiment (++,+n,-,-) | EN | Text | CoreNLP (NN) | — | .62 | [38] |
| Sentiment (+,n,-) | EN | Text | LingPipe (SVM/NB) | — | .76 | [39] |
| Sentiment (+,n,- / continuous) | EN | Text | VADER (Lexical + Rules) | — | .76 | [40] |
| Sentiment (+,n,-) | EN | Tweets | LSTM | .48 | .67 | [33] trained on [35] |
| Sentiment (+,n,-) | EN,ES | Tweets | Sentiment140 | .76 | .79 | [41] |
| Sentiment (+,n,-) | ES | Tweets | SVM (TASS2015) | .74 | — | [42] |
| Sentiment (+,n,-) | CZ | Text | LingPipe (CZ reviews) | .86 | — | [39] |

TABLE III
MODELS FOR EMOTION DETECTION FROM TEXT.

| Affect Representation | Lang | Domain | Algorithm | Train Eval. | Reference |
|-------------------------------|----------|--------|----------------|-------------|---|
| Emotion (Ekman) | Multiple | Text | WordNet-Affect | — | [31] |
| Emotion (Ekman) | EN | Tweets | SVM (hashtags) | $F_1: .37$ | [45] |
| Emotion (4 Ekman Intensities) | EN | Tweets | BLSTM+SVM | $R^2: .45$ | [46] trained on [47] |
| Emotion (VAD) | EN,ES | Text | ANEW | — | [43], [44] |
| Emotion (VADS) | EN | Tweets | BLSTM | $R^2: .24$ | [48] trained on new data (See 4a below) |

WordNet¹². As a result, the WordNet-Affect based emotion detection module is also applicable to those languages.

B. Audio Processing

This module recognizes emotions in terms of arousal and valence from speech signals¹³. It is based on the Bag-of-Audio-Words (BoAW) approach [62], trained on continuous emotionally labeled data (the *RECOLA* database [63]). RECOLA is an audio-visual database of 46 subjects during dyadic conversation in French. For each subject, a recording of 5 minutes length has been annotated time-continuously for Arousal and Valence dimensions by six different annotators (3 female, 3 male). From the 6 annotations, a single *gold standard* sequence has been computed for each dimension, using an *evaluator weighted estimator* [64].

BoAW originates from the bag-of-words approach in natural language processing. In this approach, word histogram vectors are used as a feature to classify text documents, e.g., in terms of *sentiment* or the author's *gender* [65]. For BoAW, the first step is the extraction of acoustic low-level descriptors (LLDs) from the raw waveform of the speech signal. audEERING's open-source toolkit openSMILE¹⁴ [66] is used to extract *Mel-frequency cepstral coefficients (MFCCs)* and logarithmic energy over a short audio frame of 25 ms, with a step size of 10 ms. Each 13-dimensional LLD vector is then assigned to a so-called *audio word*, i.e., a template of an LLD vector. This is accomplished through a vector quantization step using a codebook which has been learned beforehand. A random sampling [67] of 200 LLDs from the training data has proven to be suitable for the task. In the vector quantization step, Euclidean distance is taken into account.

¹²<http://polylingwn.linguistic-lod.org/>

¹³Although *audio* includes speech, music, and other acoustics, the module that we built within the MixedEmotions Toolbox is for speech. Other modules, such as music emotion may be added later to the toolbox.

¹⁴opensmile.audeering.com

TABLE IV
PERFORMANCE (CCC) OF THE AUDIO EMOTION RECOGNITION MODULE
ON THE RECOLA DATABASE.

| Database | Partition | Arousal | Valence |
|----------|-------------|---------|---------|
| RECOLA | Development | .797 | .529 |
| | Test | .722 | .452 |
| SEWA | Development | .359 | .157 |

To make the power of the histogram independent from the duration of the input segment, a histogram normalization is performed. The whole BoAW-processing is accomplished by the open-source toolkit openXBOW¹⁵ [68].

For decoding, a *support vector regressor* (SVR) with a linear kernel was trained [69]. All hyperparameters have been optimized systematically using a speaker-independent split of the database into training, validation, and test partitions [62]. The performance of arousal and valence recognition in terms of *Concordance Correlation Coefficients (CCC)*¹⁶ [70] for the RECOLA and SEWA [71] datasets are summarized in Table IV.

C. Video Processing

This module is responsible for emotion recognition (arousal/valence and Ekman's emotions) from facial gestures. The emotion recognition runs on top of face detection and tracking, facial landmark localization, head pose estimation, and face alignment. Face detection is based on a discriminatively trained deformable part model [72] which runs at approximately 8-16 fps on 720p video. Faces are tracked in a video according to standard tracking by detection. To maintain identities across these partial tracks, visual fingerprints are extracted from individual frames, and clustered by hierarchical

¹⁵<https://github.com/openXBOW/openXBOW>

¹⁶CCC is similar to the Correlation Coefficient, but it also considers the mean and variance of the two random variables.

TABLE V
FACE VERIFICATION ACCURACY OF CNN [73] FINETUNED WITH AFFINE AND SIMILARITY GEOMETRIC ALIGNMENTS ON YOUTUBE FACES DATASET.

| Original | Affine alignment | Similarity alignment |
|----------|------------------|----------------------|
| .973 | .974 | .977 |

clustering using complete linkage and cosine distance. The features are then used as activations of a convolutional neural network (CNN) [73] which is fine-tuned on the Megaface dataset [74] for similarity transform facial alignment (See Table V for the effect of the fine-tuning).

Facial landmarks are localized by an ensemble of regression trees [75] which provides decent facial point localization at real-time speed even on a single core CPU. The faces are aligned using similarity transformation. Head orientation is estimated by Random Regression Forests [76] trained on AFLW dataset [77]. Body pose is tracked using Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields [78] which can run at 10fps on an Nvidia GeForce GTX 1080 graphics card and can handle arbitrary poses, occlusion, and motion blur.

Facial expressions (sadness, happiness, surprise, disgust, anger) are estimated from aligned face regions using a CNN consisting of four convolution layers, two pooling layers, and three fully connected layers. The network achieves classification accuracy of 0.705 among five expression classes on the Facial Expression Recognition Challenge dataset [79]. More detailed facial information is extracted using the OpenFace toolkit [80] which implements a Constrained Local Neural Field (CLNF) deformable model for gaze tracking [81] and additional Support Vector Machine and Support Vector Regression models trained on the merged SEMAINE [82], DISFA [83], and BP4D [84] data for facial action unit detection.

Visual valence and arousal models were trained on the RECOLA database [63]. These models reuse activation features from the fully connected layers of the facial expression network (CNN-fc5 for the first fully connected layer and CNN-fc6 for the second). The per-frame features are compressed using PCA¹⁷, basic statistics are computed from a temporal window (mean, variance, minimum, maximum), and statistics from several neighboring frames are compressed again using PCA. The models built on these features are linear regressors trained with *Concordance Correlation Coefficients (CCC)*¹⁸ objective function and weight decay. The results on the training and validation parts of the RECOLA database from AV+EC 2016 Challenge [85] are shown in Table VI.

D. Linked Data and Knowledge Graph

MixedEmotions Toolbox intends to exploit (emotion-related) information across different sources (i.e., emotion analysers for text, audio, video). To enable this capability,

TABLE VI
PERFORMANCE (CCC) OF THE VIDEO EMOTION RECOGNITION USING CNN ON AV+EC 2016 CHALLENGE DEVELOPMENT SET. FEATURES VIDEO-APPEARANCE AND VIDEO-GEOMETRIC WERE PROVIDED AS BASELINES BY THE CHALLENGE ORGANIZERS.

| | Valence | Arousal |
|------------------|---------|---------|
| Video Appearance | .474 | .483 |
| Video Geometric | .612 | .379 |
| CNN-fc5 | .512 | .532 |
| CNN-fc6 | .498 | .585 |

Linked Data principles have been investigated to define protocols and approaches to link the information of these sources to each other [86]. In the MixedEmotions Toolbox, the JSON Linked-Data (JSON-LD) format has been used for this task (Section III-D1). The use of linked data formats allows us to easily connect resources to common sense knowledge captured in knowledge graphs such as DBpedia [50] (Section III-D2).

1) *Linked Data Representation*: The MixedEmotions Toolbox follows a linked data approach in its services. The pillars of this approach are: (i) a representation model for all types of annotations covered by the toolbox (sentiments, emotions, suggestions), (ii) a means to uniquely identify annotations, (iii) a representation format to capture those annotations, (iv) a common interface for services within the toolkit to allow communication between them, and (v) a set of tools that unites all these aspects and enables the creation of new services. This section briefly covers these aspects, focusing on the representation.

The representation model includes all the concepts in the domain (*social post*, *entity*, *emotion*) and their properties or relationships (e.g., *post has emotion*, *emotion is of category happy*). Rather than creating an ad-hoc model for each domain, linked data principles encourage reusing already existing models. These models are also referred to as ontologies, vocabularies, or specifications. There are three vocabularies that are very relevant for sentiment and emotion annotation: Marl [87] (to annotate and describe subjective opinion), Onyx [88] (to annotate and describe emotions) with interoperability with Emotion Markup Language (EmotionML) [89] and NLP Interchange Format (NIF) 2.0 [90] (a semantic format and API for Natural Language Processing services). Moreover, the Onyx vocabulary provides a meta-model of emotions, i.e., instead of defining a set of categories or dimensions for emotions, it provides a meta-model so that different models can be defined and uniquely identified. It also contains definitions for the emotion models (vocabularies) in Emotion-ML and WordNet-Affect. Hence, annotators and service developers can be specific about what emotion models they are using (e.g., Ekman's big-6 categorical model, Russel's Circumplex model, etc).

Nevertheless, these models alone may not cover all the possible needs of possible use-cases for the the MixedEmotions Toolbox. Therefore, additional concepts (e.g., suggestions, multi-results that include several entries and multimedia results) are defined, and the final proposed model (named the “MixedEmotions model”) contains existing models (Marl, Onyx, NIF) and their extensions. This model uses NIF as the

¹⁷Principal Component Analysis

¹⁸CCC is similar to the Correlation Coefficient, but it also considers the mean and variance of the two random variables [70].

foundation for annotation of NLP results. NIF also provides different URI Schemes to identify text fragments inside a string, e.g., a scheme based on RFC5147 [91], and a custom scheme based on context. To this end, texts are converted to RDF¹⁹ literals and a URI²⁰ is generated so that linked data annotations can be defined for that text. The same idea can also be applied to annotate multimedia [92]. The combination of Onyx's meta-models of emotion with the homogeneous multimedia annotation can be leveraged for automatic conversion and fusion of multimodal results [93].

To serialize these annotations, the MixedEmotions toolbox uses a common JSON-LD (JSON for Linked Data) schema. JSON-LD is a way of encoding Linked Data as JSON which provides a balance between semantic expression and ease of use for developers [94].

Moreover, this format is a good fit with the REST API that NIF defines for Natural Language Processing (NLP) services with standardized parameters. The MixedEmotions API adds several new concepts and parameters to those originally included in NIF, to cover the broad scope of the toolbox. It also establishes JSON-LD as its standard serialization format.

Lastly, these concepts are tightly integrated in the development kits and libraries provided by the MixedEmotions Toolkit. A notable example is Senpy²¹, a linked data framework for NLP services [95]. The aim of Senpy is to allow researchers to effortlessly turn their NLP analysis (e.g., sentiment and emotion analysis) into semantic web services. It also provides a series of common features that complement the services by leveraging their inherent semantics, such as automatic emotion model and format conversion, normalization of results and pipelining of several analysis. Senpy has been extensively used in the development of several modules of the MixedEmotions Toolbox.

Listing 1 (Supp. Materials: ex-linked-data.pdf) illustrates the semantic representation in a comprehensive example that includes multimodality (audio, video and text), fusion, and conversion of annotation. In particular, this example covers the analysis of the first two seconds of a video (located at <http://example.com/video.mp4>), and fusion of the three modalities. Since fusion requires all modalities to use the same dimensional emotion model, a conversion service exploits the semantic representation of emotion models in each annotation to find the appropriate conversion mechanism. As a result, the text results are converted from a categorical model to a dimensional one.

2) **Knowledge Graph (KG):** Knowledge graph theory uses graphs for the representation of concepts such as in medical and sociological texts [96]. The cumulation of such graphs can work as decision support system that can document the consequences of actions. The combination of knowledge graphs with concept models [97] led to the development of ontologies, which focused on the logical relations of concepts instead of words.

For a long time, knowledge graph theory was used for specific tasks: modeling of ecosystems or in linguistics for

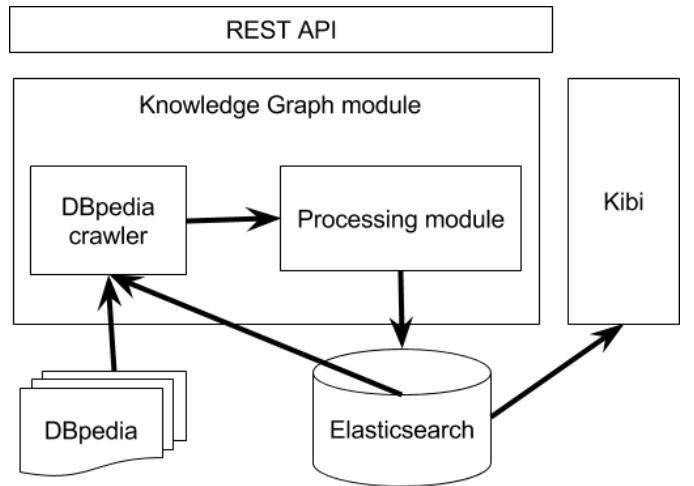


Fig. 2. Knowledge Graph module architecture.

analyzing content of books [98]. Recently, the increasing popularity of linked data and the emergence of knowledge bases made large and general purpose knowledge graphs possible, such as Google's Knowledge Graph, which is a compilation of facts and figures that provides contextual meaning to its searches [99]. In the MixedEmotions Toolbox, we provide a KG module that can be used to provide insights into relations between recognized entities using semantic knowledge from DBpedia [50]. The Entity Extraction and Linking module identifies entities mentioned in the analyzed resources, and then the KG module links them to the entities in DBpedia, so more specific information can be obtained about them (see Supp. Materials: ex-entities.png). Once the relations are extracted and filtered to keep the relevant ones only, they are stored in an Elasticsearch²² database alongside other content metadata such as emotion annotations, where they can be readily visualized (e.g., using the Kibi graph browser, see below). The resulting KG contains the extracted entities, their specifications and related information, and the relations among them. The KG module is managed by a REST API, and needs an index in the Elasticsearch database that contains both the source text and the entities extracted. It can be queried by exploiting the REST API, so other modules can retrieve parts of the graph; in addition, it can be navigated through the Kibi graph browser.

The architecture of the KG module consists of five main parts: the Database, the DBpedia crawler, the Processing module, the Web server that exposes a REST interface, and the Kibi graph browser:

- **Database:** Elasticsearch repository stores information processed by other modules as well as KG module.
- **DBpedia crawler** is responsible for crawling information from DBpedia, that is, related entities in the Database that are identified by the Entity Extraction and Linking module.
- **Processing module** filters the extracted information and splits it by type. The Entity Extraction and Linking

¹⁹Resource Description Framework

²⁰Uniform Resource Identifier

²¹<https://github.com/MixedEmotions/senpy>

²²Elasticsearch provides a distributed, multitenant-capable full-text search engine with an HTTP web interface and schema-free JSON documents.

module assigns one of the three types to the recognized entity: Person, Organization, and Location. Each type is processed separately so they can be stored in separate indexes. As the extracted information is not always ‘clean’ (it can wrongly be classified as a certain type of entity), the module applies customized filters for each type of entity to reduce the number of wrongly classified entities. Apart from writing the extracted information to the Database, the KG module automatically defines links between entities, adds the mapping of relations to Elasticsearch, and creates Kibi dashboards for each type of entity as well as a dashboard for the graph browser.

- **Web Server** allows monitoring and control of the KG module externally through a REST API.
- **Kibi graph browser** is a very powerful platform for interactive, exploratory big/streaming data discovery and alerting, with specific focus on exploration/leveraging of relationships across datasets. It performs ‘on the fly’ analytics on the collected entities and processed data stored in Elasticsearch. The Kibi graph browser provides the capability to visualize connections between entities and explore existing connections based on relations in DBpedia.

E. Social network analysis

In general, sentiment and subjectivity are quite context-sensitive [100]; The meaning of a particular piece of content (e.g., a tweet, a Facebook status, or a blog post) may only be fully understood when its social context is taken into consideration. In fact, social context has an effect on the behaviour of users in social networks [101]. Recent work has demonstrated the existence of certain patterns in relationships in social media, which is explained by several social theories [102]. One notable example is social influence [103], which pertains to behavioural changes due to perceived relationships with other people, organizations and society in general.

Detecting and characterising social contexts and the emotions that are expressed therein has multiple applications. First, the detection of the most relevant shared content (e.g., tweets or posts), users (e.g., influencers), and groups of users (communities) provides a path for micro-analysis of opinions in brand monitoring [104] and content recommendation scenarios. Second, emotion propagation patterns can be used for both analysis and prediction of expected social influence of a message [105], [106], [107], [108]. Those same patterns may also indicate false information or rumours [109]. Finally, social features can improve sentiment analysis and emotion detection [110], [111]. This can be specially relevant in microblogging based social networks such as Twitter, where the short length of the content makes the task very complex.

‘Scanner’ as a module in the MixedEmotions Toolbox that provides a standalone framework for crawling and analysing Twitter contents to perform social network and emotion analysis. It is capable of calculating different social metrics (e.g., content metrics, group metrics, temporal metrics, influence metrics). The architecture of this module is depicted in Fig.3.

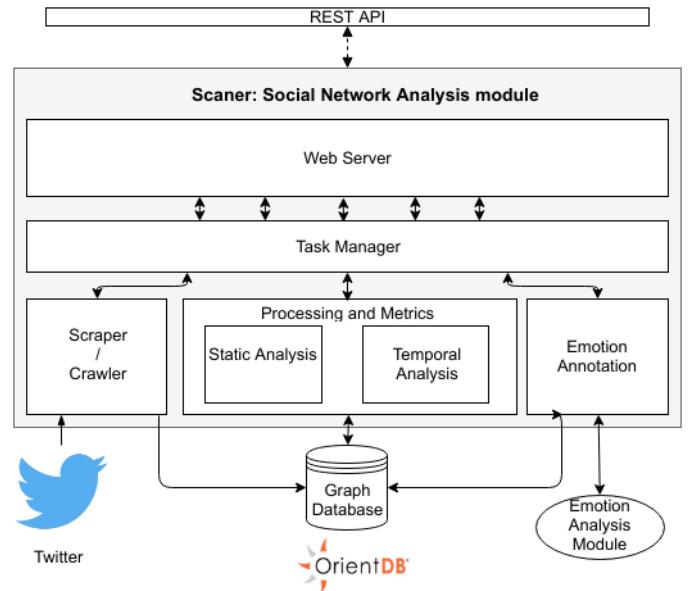


Fig. 3. Architecture of the Social Context Analysis module ‘Scanner’.

F. Decision fusion

Since within the MixedEmotions Toolbox, emotions can be extracted from diverse modalities (video, audio, text) and sources, there is a need to combine extracted results and yield a final (more reliable) estimate. For this, the decision fusion module accepts the outputs (in the MixedEmotions JSON-LD format) of modules that represent emotions in terms of continuous arousal and valence (irrespective of modality), and combines them by a weighted average of the values. The choice of classifier fusion (vs. feature fusion) is to keep modules independent of each other, and the choice of weighted average is because each modality may contribute differently to recognizing emotions (for example, it is known that valence can be recognized better via facial monitoring, while arousal can be recognized better via speech monitoring). Weights can be learned offline, set manually, or have the same values.

IV. USE CASES OF THE MIXEDEMOTIONS TOOLBOX

The MixedEmotions Toolbox has been tested in the context of three concrete use cases (Emotion-driven Smart TV, Brand Reputation Analysis, Call Center Monitoring) to verify its usefulness.

A. Emotion-driven Smart TV

In this use case, an emotion-driven recommendation engine is developed. The purpose of this engine is to use emotion signals to enhance traditional content- and user-based recommendations for TV programs. More specifically, the Apache Mahout open-source recommender in conjunction with video material published by the broadcaster Deutsche Welle is fed with emotion predictions of the MixedEmotions Toolbox. For each of Deutsche Welle’s videos, the following contents are used for the emotion analyzer:

- the video’s title and description text

- the transcription of the video's soundtrack²³
- twitter messages relating to the video's topics
- the video's soundtrack itself

For each of these contents, the distribution of emotions was calculated using MixedEmotions emotion detection modules for the appropriate modality and fed into the recommendation engine. This was done alongside classical features such as keywords and the percentage of the video duration that the viewers actually watched.

The resulting recommendations were used to present viewers of Deutsche Welle's Apple TV application with suggestions of video contents to watch from two categories:

- 1) Eudaimonic content — intriguing/challenging videos
- 2) Hedonic content — joyful/entertaining videos.

These categories are based on recent research into media consumption [112], [113]. The idea is to give viewers the possibility to choose from these two distinct categories depending on their current mood, where they either prefer purely joyful content (e.g., travel and lifestyle) or more intriguing content (e.g., documentaries about conflicts or confrontational interviews). In the Supplementary Materials (ex-social-tv.png), a snapshot of the emotion analysis of videos of Deutsche Welle's programs after fusing transcription, audio, and tweet analysis is presented. In this case, the fusion is based on the collective histograms from different modalities. If the histogram is skewed toward positive valence, the content is Hedonic, and if it is skewed toward positive arousal, it is considered as Eudaimonic.

An A/B test is conducted to verify whether the addition of emotion signals helps to identify videos that a viewer is more likely to prefer — and therefore watch to the end. 1227 users registered and 79 videos were selected as part of the experiment. After a user watches a video, a user has the option to classify it as Eudaimonic or Hedonic and the recommendation engine prepares two sets of videos based on their Eudaimonic and Hedonic contents. A 'hit' is counted when the user selects a video from the same emotional content as the previously-shown video. Overall, 9060 videos were watched. The results are presented in Table VII, and shows that, users tend to watch videos that were proposed by the emotion-driven recommendation engine to a fuller extent (99 % of Hedonic and 92 % of the Eudaimonic video's total duration was actually watched) compared to videos where the recommendation engine did not make use of emotion predictions (88 % and 86 % respectively). Moreover, the performance of classification (Eudaimonic or Hedonic) is 86 %.

In another study, also we investigated if acoustic-based emotional features of a video can help to predict the popularity of that video [114]. We have used the 'Audio processing' module to extract acoustic features. We could achieve 70 % accuracy on recognizing popular vs. non-popular content only using seven features. For more information please refer to [114].

²³using <https://github.com/MixedEmotions/MixedEmotions/wiki/m17.-Speech-to-text-by-Phonexia>

TABLE VII
THE AVERAGE PERCENTAGE OF THE SUGGESTED VIDEOS WATCHED BY USERS

| Mood Category | Without Emotions | With Emotions |
|---------------|------------------|---------------|
| Hedonic | 88 % | 99 % |
| Eudaimonic | 86 % | 92 % |

TABLE VIII
PERFORMANCE OF DIFFERENT APPROACHES FOR SENTIMENT RECOGNITION (3-CLASS TASK) IN TERMS OF UNWEIGHTED AVERAGE RECALL (UAR), EVALUATED ON TWO CZECH CALL CENTERS.

| Method | language | Call Center 1 | Call Center 2 |
|-----------------|---------------|---------------|---------------|
| (i) acoustic | Multi-lingual | .344 | .431 |
| (i) acoustic | Czech | .370 | .449 |
| (ii) keywords | Czech | .381 | .359 |
| (iii) sentiment | English | .438 | .496 |

B. Call Center Monitoring

Call center Monitoring is the second use-case, which mostly relies on emotion analysis from speech. Call centers offer a promising natural space for emotion mining and analysis. On a daily basis, each agent in a call center encounters customers with different emotions and moods. Recognition of these emotions will help to write better scripts for call center agents that can soothe negative emotions and lead to higher customer satisfaction.

To embed the emotion analysis functionality into this use case, three approaches were considered: (i) acoustic-based valence recognition with multilingual and Czech models²⁴, (ii) analysis of the automatic transcription of the audio, based on the list of pre-defined positive and negative keywords and phrases, and (iii) sentiment recognition on the translation of the transcriptions using the statistical machine translation (SMT) module (Section III-A4b). This later approach is an extension of approach (ii) using methods of natural language processing that consider also the context of the utterance. In this case, we used the Phonexia sentiment analyzer, which is a Long Short-Term Memory Recurrent Neural Network (LSTM-RNN) fed with word2vec word embeddings²⁵. The system produces the posterior probability of positive sentiment for each sentence, which is then mapped to one of the sentiment classes (positive, negative or neutral). In the Supplementary Materials (ex-call-center.png), we provided a snap shot of this tool.

Acoustic-, keyword- and sentiment-based systems were evaluated on Czech call center data. Transcriptions were automatically translated to English so that the above-mentioned English sentiment analyzer (which is trained on English corpora) can be applied. The results for 3-class sentiment recognition (positive, neutral, negative) are provided in Table VIII. As the results suggest, sentiment analysis on the translated transcriptions outperforms the acoustic- and keyword-based systems.

²⁴<https://github.com/MixedEmotions/MixedEmotions/wiki/m23.-Audio-Emotion-extraction-by-Phonexia>

²⁵<http://www.fit.vutbr.cz/~imikolov/rnnlm/>

C. Brand Reputation Analysis

Brand Reputation analysis is the third use-case that uses the MixedEmotions Toolbox to implement an application for the assessment of the perceived reputation of a brand or product on the web. Its main objective is to mine selected sources of information and provide human interpretable results that can be investigated by the person in charge of the brand.

This use-case monitors Twitter and YouTube, and processes textual and audio contents to evaluate sentiments and emotions. Entities and the distribution of languages are also extracted. Human-readable results are visualized at real-time using Kibi to compare between different brands and to study emotions and sentiments regarding different dimensions such as hashtags, YouTube channels, or locations. A snapshot of the Kibi for emotion distribution for a Brand is provided in the Supp. materials (ex-brand-reputation.png).

V. CONCLUSIONS

In this paper, we introduced a free, open-source, and multimodal toolbox for emotion analysis: the ‘MixedEmotions Toolbox’. The toolbox includes functionalities for text, audio, and video processing with the aim of emotion recognition. Three use cases were described: Emotion-driven Smart TV (emotion-based recommendation), Brand Reputation Analysis (monitoring reputation of a brand from tweets and YouTube videos), and Call Centre Monitoring (monitoring emotion of customers in a help-desk setting). In the future, we hope to see contributions to the release and will ourselves update further functionality aiming beyond improved robustness and increases in efficiency — multimedia data is often ‘big’, but it is always emotional!

ACKNOWLEDGEMENT

 The research leading to these results has received funding from the European Union’s Horizon 2020 Programme research and innovation programme under grant agreements No. 644632 (MixedEmotions).

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