ConAn: A Usable Tool for Multimodal Conversation Analysis

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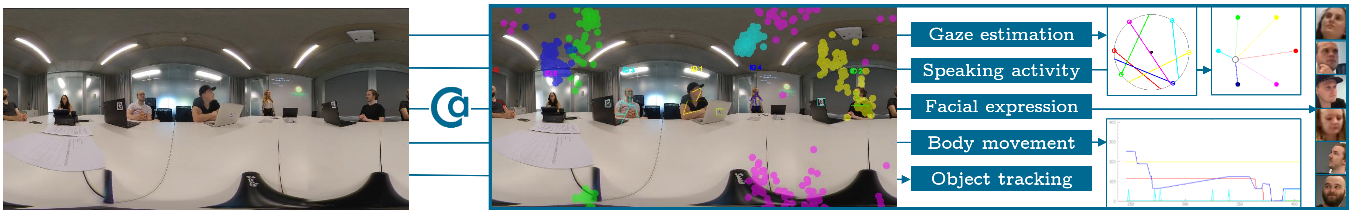

Figure 1: *ConAn* – our graphical tool for multimodal conversation analysis – takes 360 degree videos recorded during multi-person group interactions as input. *ConAn* integrates state-of-the-art models for gaze estimation, active speaker detection, facial action unit detection, and body movement detection and can output quantitative reports both at individual and group level, as well as different visualizations that provide qualitative insights into group interaction.

ABSTRACT

Multimodal analysis of group behavior is a key task in human-computer interaction, and in the social and behavioral sciences, but is often limited to more easily controllable laboratory settings or requires elaborate multi-sensor setups and time-consuming manual data annotation. We present *ConAn* – a usable tool to explore and automatically analyze non-verbal behavior of multiple persons during natural group conversations. In contrast to traditional multi-sensor setups, our tool only requires a single 360° camera and uses state-of-the-art computer vision methods to automatically extract behavioral indicators, such as gaze direction, facial expressions, and speaking activity. As such, our tool allows for easy and fast deployment and supports researchers in understanding individual behavior, group interaction dynamics, and in quantifying user-object interactions. We illustrate the benefits of *ConAn* on three sample use cases: conversation analysis, assessment of collaboration quality, and impact of technology on audience behavior. Taken together, *ConAn* represents an important step towards democratizing automatic conversation analysis in HCI and beyond.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**.

KEYWORDS

graphical user interface, conversation analysis, non-verbal behavior, group interaction

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1 INTRODUCTION

The need to sense, analyze, and understand conversations within groups of people arises in a range of different areas in HCI, computer-supported cooperative work (CSCW) as well as the social and behavioral sciences. In HCI, conversation analysis is important for applications such as conversational agents, human-robot interaction, or virtual and augmented reality [61, 77]. However, conversation analysis is still a largely manual and thus time-consuming, cumbersome, and error-prone process both to setup and to perform. For example, Chattopadhyay et al. [24] manually analyzed observations, interviews, and usage logs as well as video recordings to study group behavior while Brown et al. [20] studied phone conversations using manual labeling of more than 24h of video material. In addition, researchers have argued that manual coding of videos is likely to be influenced by the coder, resulting in annotation bias [70].

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Modality	Usage
Eye Gaze	disruptive impact of mobile interactions [58], rapport detection [66], emergent leadership detection [18, 19, 63], social plane during interaction [73], mobile internet search as a part of conversation [20], interpersonal relationships at work [91], shared attention [61], classroom attention [75], human-robot-interaction [28], gaze cuing [71], social anxiety disorder [84], autism spectrum disorder [80], turn-taking [45], conversational engagement [16], social phobia [9], work group mood [12]
Speaking Activity	paralinguistic persuasion [94], emergent leadership detection [18, 63], rapport detection [66], personality trait prediction [51, 69], collective intelligence [32, 102], emotion recognition [62], prediction of extraversion trait [51], Meeting Mediator: feedback for group collaboration [49], interspeaker influence [23]
Body Pose and Hand Movement	social rank [100], attention detection [1], assessment of public speaking skills [25], in-class student participation [76], instructional communication [93], work group mood [12], behavior imitation [30], group emotional contagion [11], teaching behavior [46]
Facial Expression	social rank [100], rapport detection [66], classify human-human versus human-machine interaction [67], collective intelligence and group satisfaction [26], bias detection [50], group emotional contagion [11], autism spectrum disorder [80], behavior imitation [30]
Environment Tracking*	in the wild understanding [20], technology use in conversations [72, 89], device tracking [58], device logs [24]

Table 1: Common modalities in conversation analysis. * short list of factors mainly relevant for the HCI domain.

Analysis challenges due to the variability of human behavior are amplified in interactions between multiple people, and thus, the analysis of multiple modalities is required, such as speech, body language, and gaze. This has triggered research to move away from manual, time-consuming analysis, as well as the need for specialized hardware [16, 24] towards using computational methods for automatic analysis that only require off-the-shelf sensors [19, 82]. Over the last decade, various computational methods have been developed that enable researchers to automatically extract conversation characteristics from audio and video footage, e.g., rapport [66], leadership [63], and eye contact [8, 43, 64]. However, these methods have been developed independently and therefore, are largely inaccessible to the aforementioned research communities. Finally, the analysis of individual characteristics by using separate tools makes it challenging to jointly analyze and identify similarities, correlations, or patterns across modalities and people. Thus, the deployment of multiple sensors and the usage of multiple analysis tools is hard [40].

To address these limitations, and democratize the use of multimodal conversation analysis in HCI and beyond, we introduce *ConAn* – a usable tool that helps researchers in exploring and automatically analyzing non-verbal behavioral data of multiple people during natural group conversations. To support usability and foster easy deployment, our tool only requires a single 360° camera and integrates state-of-the-art algorithms for eye gaze estimation, action unit detection, speaker diarization, object tracking, and non-verbal gestures based on the body pose under a single graphical user interface. The development of *ConAn* was informed by a literature review to identify major features and dominant use cases of automatic conversation analysis across multiple disciplines. We illustrate the application of our tool by discussing multiple use cases it enables: general conversation analysis including observations on the disruptiveness of mobile phones, assessment of collaboration quality on a recorded collaboration task between three participants, and a small study on the impact of technology on audience behavior by comparing two videos with the same scenario, one with and the other without devices. We hereby showcase the use and flexibility for researchers within HCI but also how *ConAn* could be used for general social and behavioral research.

In summary, this work contributes an open-source tool that allows to easily study conversations with multiple people using a single 360° camera. We offer a wide range of state-of-the-art non-verbal and verbal analysis possibilities, such as gaze estimation and speaker diarization. Our tool is also equipped with the functionality to understand the impact of technologies surrounding conversation partners. This allows HCI researchers to rapidly analyze group scenarios without the need for elaborate camera and microphone setups. Moreover, the tool can serve as a screening tool for social psychologists. In conjunction with providing researchers with the open-source tool, we also provide 4 videos as a showcase evaluation highlighting the easy use of our setup and tool.

2 RELATED WORK

Conversation analysis is conducted in many domains, such as human resources development, education, or HCI. In the following, we first discuss the modalities that current analyses commonly use. Afterwards, we discuss how conversation analysis is used in HCI to better understand the interplay between humans and technology. Finally, we present currently available conversation analysis tools.

2.1 Modalities in Conversation Analysis

A number of fields use conversation analysis such as psychology [9, 84], human resources development [6, 53], learning analytics [73–75, 93], social skills training [13], or human robot interaction [28, 61]. Despite many similarities in terms of the general approach, we identified specific differences in the type of modalities that these fields primarily use, as well as the specific features that are extracted from them, see Table 1 for an overview.

Eye Gaze, usually in the form of eye contact, provides rich information on conversational behavior, such as engagement [16] or workgroup mood [12]. Eye gaze can also be used to infer the presence of personality traits [42], social anxiety disorder [84] or autism spectrum disorder [80]. Gaze further provides insights into how individuals behave as part of the group in terms of turn taking [45] or how pairs of people interact with one another, cf. [65].

Speaking Activity is widely studied during social interactions, including inter-speaker influence [23], paralinguistic persuasion [94], but also in the context of interaction mediation systems that try to improve collaboration [49]. Furthermore, active speech is closely correlated with non-verbal features like gestures [33] and eye contact [41, 48, 78]. These close connections indicate that social interaction understanding can benefit from jointly analyzing speaking activity with visual feature channels. While single-modal approaches only using audio [7, 35, 98] or video [36, 85] work well, multi-modal approaches are even more promising [10, 27, 37].

Body Pose and Hand Movement are important in conversations, e.g., for speakers to convey their message [15], in instructional communication [93], or for assessing of public speaking skills [25]. While body and hand gestures can repeat verbally stated arguments, they do not always need to [15]. Therefore, it is important to not only understand the verbal communication but also the accompanying non-verbal communication. For instance, deictic gestures are a core element of non-verbal expressions to guide the partners' attention [21, 38, 59]. Body and hand pose are also important for understanding classroom participation in educational settings [1, 44]. Various computer vision methods have been proposed to determine the human pose based on a RBG image [22, 90, 92].

Facial Expressions can both uncover general mood within a group but also information about individuals, such as the social rank [100] or low rapport detection [66]. Other researchers extracted group features like satisfaction [26] and emotional contagion [11]. Facial expressions were also shown to be usable for uncovering general personality disorders, e.g., the reaction times of facial expressions can detect potential threats to self or to close others [50]. Some approaches for extracting facial expressions make use of depth cameras to better support the recognition [52, 99] while other approaches can even extract the underlying action units such as [4, 54, 86].

2.2 Conversation Analysis in HCI

Wobbrock [101] provides an excellent review of how computer and technology in the environment can distract and impair people. Such impacts are for instance mobile phone use in group settings [89] or even in bed [81]. To understand these impacts, HCI research used a wide range of features based on conversation analysis. For instance, Mayer et al. [58] used gaze direction combined with video observation and interviews to understand the impact of incoming calls on a face-to-face conversation. Moreover, the quality of support induced by technology can be measured. For instance, Bednarik et al. [16] used only gaze to measure engagement in multi-group video calls and Chattopadhyay et al. [24] studied group behavior using observation, interviews, and usage logs in combination with video recordings. Brown et al. [20] analyzed mobile search in everyday conversations via video recordings of phone use and conversation transcripts between participants. Based on these insights, social disruption can be improved during design time [68].

2.3 Conversation Analysis Tools

In an attempt to reduce the complexity associated with recording and analyzing social behavior, several toolkits were proposed in a variety of scenarios [60, 83, 87]. We summarize the most relevant toolkits that apply to conversation analysis in Table 2.

The Social Signal Interpretation (SSI) framework [96] supports synchronized recording from multiple sensors as well as plug-in detection algorithms as a basis for behavior analysis. Complementary to SSI, NOVA [14, 39] focuses on the annotation process of multimodal behavior and provides functionalities for joint human-machine annotation. As NOVA is specifically built for the annotation use case, it does not provide visualizations or summary statistics for group behavior dynamics based on gaze behavior or speaking distribution which allow for a rapid, user-friendly understanding of recorded interactions. Based on the NOVA and SSI frameworks, more specialized tools answer the need for use case-specific functionalities [5, 88]. For instance, TARDIS [5] is targeted at (dyadic) job interview training in human-avatar interactions and offers playback of recordings obtained with webcam, kinect and microphone along with visualizations of annotations. On the other hand, MultiSense [88] specializes on the use case of psychological distress analysis in dyadic interactions, providing online- as well as offline feedback. Recently, Stefanov et al. [87] introduced OpenSense: a real-time multimodal acquisition and recognition system of social signals. OpenSense offers different components which can be loaded in a pipeline editor for selecting modalities of interest for each use case. Similar to NOVA, OpenSense supports analyzing multiple modalities with out-of-the-box visualizations, but needs separate pipelines for multiple subjects and therefore does not provide visualizations of group dynamics.

In summary, while several frameworks applicable to multimodal conversation analysis have been proposed, none of these frameworks provides a user-friendly, out-of-the-box solution for group interaction analysis. This is due to the lack of explicit support of a simplified sensor setup (e.g., a single 360° camera) as well as the ability to use case-specific analyses and visualizations (e.g., eye contact and speaking distribution). In contrast, *ConAn* provides an out-of-the-box solution for group behavior analysis with a simplified sensor setup and key analysis and visualization functions. At the same time, *ConAn* maintains flexibility via a modular design.

3 CHALLENGES IN MULTIMODAL GROUP INTERACTION ANALYSIS

The main challenge in conversation analysis is the lack of available datasets which in turn is due to the need for time-consuming data annotation and elaborate multi-sensor setups. For instance, Müller et al. [66] used eight cameras and four microphones, resulting in 12 separate recording devices which needed to be synchronized and oriented towards pre-defined seating positions of participants. Likewise, Beyan et al. [19] used four cameras and microphones, and an additional camera capturing the whole scene for data annotators. These controlled data collection approaches prevent research from being conducted in settings analogous to real-life situations.

Even though a 360° camera overcomes the aforementioned challenges, it also poses a new technical challenge: the lens distortion.

Name	Target Use Case	Modalities	Open Source	Multi-Platform	360° Support
MutualEyeContact [83]	Dyadic Interaction Analysis	Gaze, Facial Expressions	✗	Windows	✗
SSI [96]	Multimodal data recording and feature extraction	Extendable multi-sensor recording framework	✓	Windows*	✗
NOVA [14]	Annotation & cooperative machine learning	Extendable annotation framework	✓	Windows	✗
MultiSense [88]	Analysis of dyadic counseling interactions	Speech, Body, Gaze, Face	✗	Windows	✗
TARDIS [5]	Job interview training	Speech, Body, Gaxe, Face	✗	Windows	✗
OpenSense [87]	Multimodal data recording and feature extraction	Gaze, Speech, Body Pose, Head Gestures, Facial Expressions, Music	✓	Windows	✗
ConAn	Group Interaction Analysis	Gaze, Speaking Status, Facial Expressions, Body Pose, Object Tracking	✓	✓	✓

Table 2: Conversation Analysis Tools (* Linux & Mac via mobileSSI https://github.com/hcmlab/mobileSSI)

To be able to extract face crops as input to various models, a perspective transformation has to be performed with the center of each face as a reference point. Consequently, each subject's position needs to first be detected and tracked. To allow for people to move freely while still being able to determine their field of view (FoV) a geometric model of the room is necessary. In particular, the position of each subject needs to be set as the starting point for their gaze vector which then needs to be projected back onto the image plane. Without a geometric model each subject needs to remain in a fixed position, as e.g. in Müller et al. [64] for eye contact detection. Moreover, the design and usability of a graphical user interface (GUI) needs to be in line with the desired task to fulfill, while still being general enough for different scenarios. For multimodal conversation analysis, the main interest lies in the interaction between conversation partners. However, not many visualizations for interaction analysis on a group level have been proposed so far. On the other hand, many non-verbal feature extraction models exist, but each model requires a separate pre-processing pipeline and therefore also adds processing time.

Overall, the identified key challenges are the supported technical collection setup requiring complex processing steps, at present limiting group behavior recording and analysis to experts, as well as the conceptual design of a usable GUI with intuitively understandable visualizations and key modalities selected based on their importance for the target use case.

4 DESIGN OF *CONAN*

Our literature review revealed that conversation analysis is done using four key modalities to extract a multitude of insights into the individual conversation partners, the relationships between them, as well as overall insights into the conversation. However, conversation analysis is mostly a tedious and time-consuming task. At the same time, we discussed how current advances in computer vision and machine learning allow for automatic extraction of the modalities upon which these conversation insights are built.

In the following, we present *ConAn*: a tool that provides state-of-the-art machine learning models in an easy to use GUI, see Figure 1 and 2, enabling researchers to perform fast conversation analysis. Time is of the essence, especially during rapid prototyping and design sessions; both common tools in the HCI domain. Because our system requires only footage from a single 360° camera to capture all salient aspects of a conversation, users overcome the limitations of time-consuming annotation procedures.

Our system is designed to take every 360° video in an equirectangular projection and conversation audio as input. On this video and audio we then perform several pre-processing and extraction steps to ultimately provide them to the user in a GUI. Moreover, we developed *ConAn* using Qt[1] for cross-platform support. In the following, we discuss in detail which models and tools we used. However, our system structure is modular and allows for the replacement of individual models in the upcoming years to make use of the latest developments and advancements in machine learning and conversation analysis.

The source code for *ConAn* is available under MIT license via our git repository[2]. This allows other researchers to effectively and efficiently perform conversation analysis and thus, spark new investigations to improve the interplay between humans and technology.

4.1 User Interface

For usability we split the GUI into areas each with its own theme. On the left side of the upper half (see Figure 2 I) the video is displayed. We use video overlays to display labels for all participants, their body pose and gaze targets, as well as detected object locations. These overlays are visualized in Figure 3a, 4c, and 3e respectively, and can be toggled on or off at the control panel on the left side of the video (see Figure 2 II). A multi-segment selector is positioned below the video (see Figure 2 III). By default, the whole video is selected in one segment. By dragging the green and red separators, the start and end of the segment can be changed. Additional segments can be added by double-clicking on the empty region while removing a segment is possible by double-clicking on an existing segment. Below the multi-segment selector is a play/pause button and a standard video timeline slider.

The lower half, as shown in Figure 2 IV, consists of multiple tabs, with a separate tab for each of the five analyzed modalities. For each modality we display a set of aggregated features, as well as a dynamic visualization of the underlying data. If the selected

[1] https://www.qt.io/

[2] https://www.perceptualui.org/publications/penzkofer21_icmi/

segments are changed (via Figure 2 III), aggregated features are updated accordingly. Following [95], the data of all subjects is displayed as default, but the visualization of each subject can be hidden or shown again with the corresponding checkbox in Figure 2 II.

In the eye gaze tab (see Figure 3b) the yaw gaze of each subject and their position is visualized from a top-down view to enable the users of *ConAn* to capture eye contact behavior at first glance. Additionally, features calculated based on the amount of tracked frames, indicate various measures, including the relative time a subject is looked at by others, the time a subject spends looking at other people, the amount of time a subject is not looking at others, and a subject’s ratio between being watched and looking at other people. These features are commonly used for conversation analysis tasks, such as emergent leadership detection [63].

The distribution of speaking time is visualized dynamically, i.e. the total amount up to the current frame, with a moving circle indicating the balance of group conversation (see Figure 3d). This design was based on a real-time feedback application for enhancing group collaboration [49]. Speaking features commonly used in previous work [66] are extracted and displayed next to the graph. Features are composed of the total amount of time a subject is speaking in relation to the video length, the number of speaking turns, where one speaking turn is defined as the consecutive time a person is actively speaking, the average duration of all such speaking turns, and the average number of speaking turns per minute.

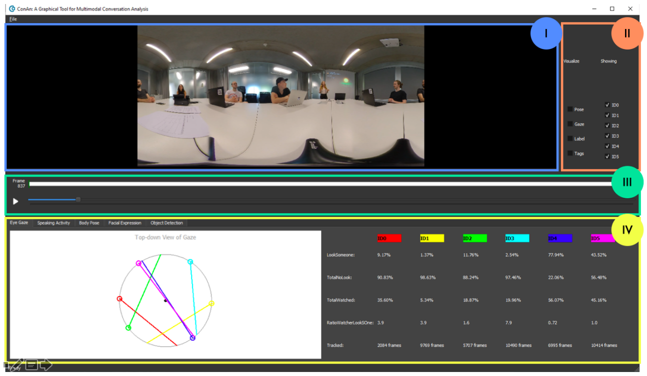
Figure 3f shows that the absolute body movement is displayed dynamically over time in terms of euclidean distance between first and current frame position, similar to [95]. Additionally, the frame number with the largest body activity is shown as a variable to enable users to quickly select interesting time segments. For hand movement, we selected three features, namely the relative time both hands were above the table, the relative time the movement of both hands exceeded a velocity threshold, and the hand velocity in the current frame, which is defined as the change of hand positions between current and last frame.

In the facial expression tab, similar to [4], cropped face images of each subject are displayed to highlight the detected facial expressions as coded by the Facial Action Unit Coding System (FACS)[3]. With our selected approach we are able to extract 12 different action units, for each of which the detected probabilities in the current frame are shown next to the image of the respective participant (see Figure 4b).

The movement of objects, similar to the visualization in the body movement tab, is displayed in a dynamic line graph (see Figure 4d). Each object has a unique tag id, which can be supplemented with available context information in an editable text field next to each tag. Additionally, the percentage of tracked frames versus overall video frames is shown on the right.

4.2 Gaze Estimation

For gaze estimation in-the-wild various options are available, including Gaze360 [47], OpenGaze [103], OpenFace [4], and RT-GENE [34][4]. While considering our application, Gaze360 [47] seems to fit best, the results were not satisfying. Thus, we finally decided to use RT-GENE [34]. In addition to feeding each video frame to the model, we also input a version of the frame where the left side and the right side are wrapped together. This enables us to detect when a person moves over the edge of the video, as none of the models account for this. Moreover, as this is a single frame estimation, we then track all subjects throughout the video using a minimal euclidean distance heuristic. Finally, to reduce outliers and noise due to the single frame estimation, we apply a rolling average window with a window length of $\frac{1}{3}$ of a second (10 frames at 30FPS).



	ID0	ID1	ID2	ID3	ID4	ID5
LookSomeone:	9.17%	1.37%	11.76%	2.54%	77.94%	43.52%
TotalNoLook:	90.83%	98.63%	88.24%	97.46%	22.06%	56.48%
TotalWatched:	35.60%	5.34%	18.87%	19.96%	56.07%	45.16%
RatioWatcherLookSOne:	3.9	3.9	1.6	7.9	0.72	1.0
Tracked:	2084 frames	9769 frames	5707 frames	10490 frames	6995 frames	10414 frames

Figure 2: System *ConAn*: layout of user interface.

From the gaze direction, we can then visualize information such as if the person is engaged in the conversion or if persons are looking at each other.

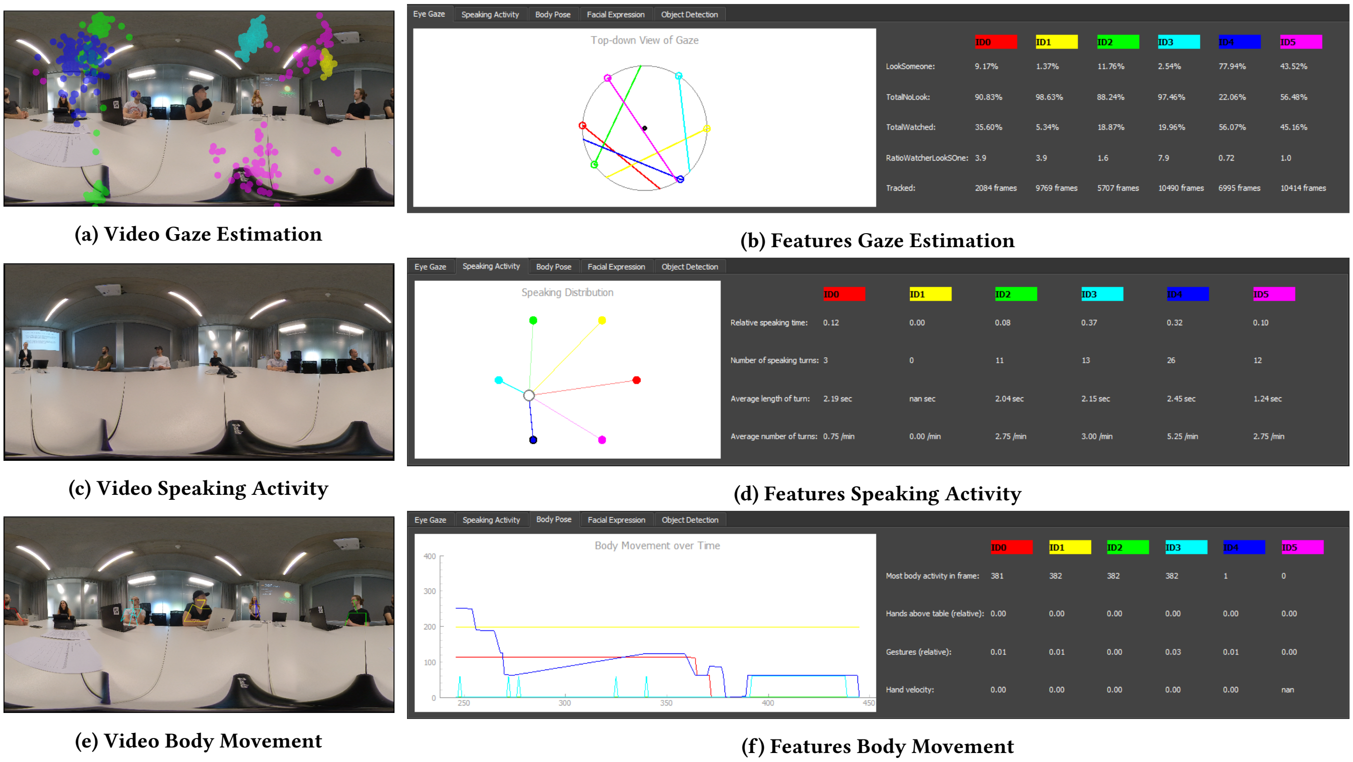
4.3 Body Movement

To be able to analyze body movement, a person’s body pose has to be detected first. While there has been a lot of research concerning this task, e.g., DeepPose [92], PandaNet [17], or OpenPose [22] proved to be the most easily accesible by providing a variety of pretrained models. OpenPose is a multi-person keypoint detector that is runtime invariant to the number of people in one frame. For our case, we used the 18-keypoint model, which takes the full frame as input and jointly predicts anatomical keypoints and a measurement for the degree of association between them. Based on the predicted degree of association keypoints are assigned to each person yielding a 2D skeleton, as can be seen in Figure 3e. Then, each identity is tracked throughout all frames of the video with a minimal euclidean distance heuristic. As the neck keypoint of each subject was the most consistently detected, its location was used to calculate overall body movement by taking its relative euclidean difference between frames. The location of both wrists is further used to track hand movement. Today’s 3D skeleton estimation models do not take fingers into account; however, when using OpenPose [22] the 2D joint estimation could be extended to detect fine grained hand poses such as reading a book, relaxed, and prayer [2].

4.4 Facial Action Unit Detection

Facial action units are based on an anatomical analysis of the face and can be described according to the (FACS) defined by Ekman et al. [31]. There are many different options available for detecting

[3] https://www.cs.cmu.edu/~face/facs.htm
[4] https://github.com/Tobias-Fischer/rt_gene/



(a) Video Gaze Estimation

	ID0	ID1	ID2	ID3	ID4	ID5
LookSomeone:	9.17%	1.37%	11.76%	2.54%	77.94%	43.52%
TotalNoLook:	90.83%	98.63%	88.24%	97.46%	22.06%	56.48%
TotalWatched:	35.60%	5.34%	18.87%	19.96%	56.07%	45.16%
RatioWatcherLookSOne:	3.9	3.9	1.6	7.9	0.72	1.0
Tracked:	2084 frames	9769 frames	5707 frames	10490 frames	6995 frames	10414 frames

(b) Features Gaze Estimation

(c) Video Speaking Activity

	ID0	ID1	ID2	ID3	ID4	ID5
Relative speaking time:	0.12	0.00	0.08	0.37	0.32	0.10
Number of speaking turns:	3	0	11	13	26	12
Average length of turn:	2.19 sec	nan sec	2.04 sec	2.15 sec	2.45 sec	1.24 sec
Average number of turns:	0.75 /min	0.00 /min	2.75 /min	3.00 /min	5.25 /min	2.75 /min

(d) Features Speaking Activity

(e) Video Body Movement

	ID0	ID1	ID2	ID3	ID4	ID5
Most body activity in frame:	381	382	382	382	1	0
Hands above table (relative):	0.00	0.00	0.00	0.00	0.00	0.00
Gestures (relative):	0.01	0.01	0.00	0.03	0.01	0.00
Hand velocity:	0.00	0.00	0.00	0.00	0.00	nan

(f) Features Body Movement

Figure 3: The in depth view of the gaze, speaking, and body features in the view (IV) of *ConAn*.

facial action units: OpenFace [4], AU R-CNN [54], or combining face alignment with action unit detection, as proposed in JAA-Net [86][5]. These approaches mainly differ in the amount of action units they are able to extract. Therefore, to maximize the number of extractable action units, we decided to use JAA-Net [86]. We trained JAA-Net on DISFA: a database of facial action units including intensities, made available by Mavadati et al. [56, 57]. After training, the model is able to perform face alignment by predicting facial landmarks, as well as global and local feature extraction for facial action units. The model takes cropped face images as input, which we extracted from the video frame for each subject based on the RT-GENE [34] head center prediction. The model then outputs activation maps, predicted landmarks, and predicted probabilities of 12 different action units: inner and outer brow raiser, brow lowerer, upper lid raiser, cheek raiser, nose wrinkler, lip corner puller, which is also known as a smile, lip corner depressor, chin raiser, lip stretcher, lips part, and jaw drop. We display these predicted probabilities as seen in Figure 4b. The action units are defined as present if the probability exceeds $\frac{1}{2}$ and the amount of frames in which a specific action unit is present for each person is included in the export file.

4.5 Speaker Activity Detection

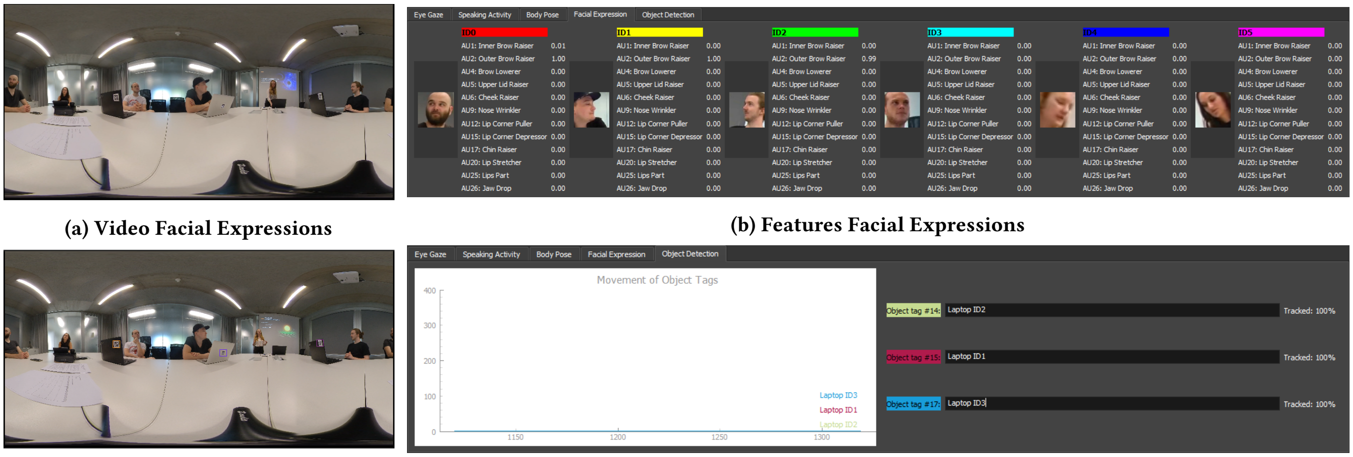
As *ConAn* can be employed in a large variety of environments, the speaker activity detection should be able to handle this variety. We therefore chose to employ the most recent, publicly available, state-of-the-art method [3] on the AVA-ActiveSpeaker dataset [79], as this dataset features a large variety of environments and speaker appearances. The method of Alcázar et al. [3] consists of two steps. In the first step, short audio snippets and corresponding individual face tracks of each potential speaker are analysed separately using CNNs. A second step models the temporal context and the relation between potential speakers using a LSTM network. We use code and pre-trained models provided by Alcázar et al. [3][6]. The face tracks are obtained from RT-GENE detections [34]. We observed that while speakers are usually assigned a higher probability than non-speakers in the softmax output of the method from Alcázar et al. [3], these probabilities are usually below $\frac{1}{2}$, leading to misclassification. To circumvent this issue, we assign an active speaker label to the user with the highest output probability. The sum of active speaker frames for each person is allocated as total speaking time and the resulting overall speaking distribution between speakers is visualized in a balance graph (see Figure 3d). Additionally, current active speakers are highlighted with a black frame.

4.6 Object Tracking

Object tracking is a complex task for which most approaches follow the tracking-by-detection scheme, where they first need to detect objects and then find the corresponding tracklets over time. As the users of *ConAn* are most likely able to define their own study procedures we decided to simplify this task by employing object tracking for pre-selected tags, as used by [58]. In particular, for our showcases we used the visual fiducial system AprilTag 2 [97],

[5] https://github.com/ZhiwenShao/PyTorch-JAANet

[6] https://github.com/fuankarion/active-speakers-context



(a) Video Facial Expressions

(b) Features Facial Expressions

	ID0	ID1	ID2	ID3	ID4	ID5
AU1: Inner Brow Raiser	0.01	0.00	0.00	0.00	0.00	0.00
AU2: Outer Brow Raiser	1.00	1.00	0.99	0.00	0.00	0.00
AU4: Brow Lowerer	0.00	0.00	0.00	0.00	0.00	0.00
AU5: Upper Lid Raiser	0.00	0.00	0.00	0.00	0.00	0.00
AU6: Cheek Raiser	0.00	0.00	0.00	0.00	0.00	0.00
AU9: Nose Wrinkler	0.00	0.00	0.00	0.00	0.00	0.00
AU12: Lip Corner Puller	0.00	0.00	0.00	0.00	0.00	0.00
AU15: Lip Corner Depressor	0.00	0.00	0.00	0.00	0.00	0.00
AU17: Chin Raiser	0.00	0.00	0.00	0.00	0.00	0.00
AU20: Lip Stretcher	0.00	0.00	0.00	0.00	0.00	0.00
AU25: Lips Part	0.00	0.00	0.00	0.00	0.00	0.00
AU26: Jaw Drop	0.00	0.00	0.00	0.00	0.00	0.00

(c) Video Object Detection

(d) Features Object Detection

Object tag #14: Laptop ID2 Tracked: 100%

Object tag #15: Laptop ID1 Tracked: 100%

Object tag #17: Laptop ID3 Tracked: 100%

Figure 4: The in depth view of the facial expression and object detection features in the view (IV) of *ConAn*.

where the tag positions are extracted with their tailored detector. For data collection, tags with a unique id are placed on the objects of interest. The detections for each frame can then be easily combined to object tracklets based on their specific tag ids. We visualize these tracklets in a dynamic object movement graph (see Figure 4d) and overlay the video with each tag position (see Figure 4c).

4.7 Export and Comparison

For further usability, we support users with a feature to export the selected sequences to a comprehensive report. The exported csv-files are split into gaze-, pose-, facial-, speaker-, and object-detection data. Additionally, all features that were displayed while using our tool, are recalculated based on the selected segments and exported as a json file. With these files users are able to compare conversation analyses of different videos side-by-side, facilitating studies including control groups, as well as longitudinal studies which require accumulating analyses over time.

5 EVALUATION

In the following, we present three use cases that highlight the variety of possible analyses, as well as potential users of *ConAn*, including researchers in the fields: HCI, social and behavioral science, and learning and education. All four 360° videos are recorded on an Insta360 One X. The videos of the three showcases are available for research purposes[7]. This will allow others to a) test the tool in depth but also to b) test new algorithms in the extraction pipeline.

5.1 General Conversation Analysis

In this video, a conversation between four participants was recorded. In order to simulate the distracting conditions of an in-the-wild exchange, the conversation took place outside and was intentionally interrupted by repeated phone calls to a single participant. After declining the first four calls, the participant answered the fifth call, upon which the recording comes to an end. This showcase highlights the disruptiveness of mobile phones in natural interactions, which has been studied mainly via interviews [89] or manual annotations [72], and is an important consideration for mobile interaction design processes [58].

After loading the data, the eye gaze tab is enabled, showing the user which participants are looking at each other in the current frame (see Figure 3b). Combining this view with *ConAn*’s other modalities, e.g. speaking activity or body movement, allows for holistic analysis of different variables related to conversation and group dynamics: in this case, the disruptiveness of mobile phones can be seen most prominently in the fact that the person receiving the phone calls had the least speaking activity. The person who looked at all the other participants the most, i.e. for 67% of the time, was also the one exhibiting the most positive facial affect (indicated by AU12 [66]) and was looked at by others only 34%, whereas the person being looked at the most (43%) only looked at other people for 18% of the time. The participant that talked the most was being looked at the least. These observations can be further compared with visual study of the interaction. For example, the person that was looked at the most had the most apparent body movement, as his hands remained on the table during the entire conversation, while the other subjects kept their hands below the table for most of the duration, and therefore exhibited less gesturing that would draw the attention of other people. However, one subject’s eye gaze was only tracked for 65% of frames, as can be directly seen within the tab (see Figure 3b), which is another important factor for consideration in the overall evaluation.

5.2 Assessment of Collaboration Quality

For assessment of group collaboration quality, we recorded a video in which three participants are engaged in a group collaboration task. In detail, the desert survival simulation [29], also known as the desert survival task, asks the participants to simulate a scenario in which they just crash-landed with a plane in the desert and need to rate 15 available items based on their importance for survival. Survival tasks are commonly used in the social and behavioral

[7] https://www.perceptualui.org/publications/penzkofer21_icmi/

sciences to analyze group behavior, such as detecting emergent leaders [82], or individual personality traits based on behavior in groups [55].

Upon loading the data in *ConAn*, the user observes in the first tab, eye gaze, that two of the three subjects have a similar amount of being watched (29% and 38%), as well as of looking at other people (36% and 25%), far exceeding the relative times for the third participant (0.12% and 12%, respectively). In the speaking activity tab, the user also observes that the two subjects additionally share the highest amount of speaking time (41% and 40%), an unsurprising finding, as in general the person speaking is most often watched by the others [66]. In the subsequent tabs, the user sees that body movement, specifically hand gesturing, and facial action units were similar for all participants. Based on these observations, the user may wish to further investigate the two subjects with the highest eye contact and speaking activity to determine emergent leadership and/or dominance as a personality trait.

5.3 Impact of Technology on Audience Behavior

The third use case comprises two videos of different presentations given by the same presenter to the same five audience members. In one presentation the audience had their powered-on laptops on the table, while in the other, everybody listened without accessing their personal devices: comparing extracted non-verbal behavior features between these videos therefore mimics a study setup with technology as the independent variable, a topic currently investigated by researchers in HCI in many different social scenarios [16, 24, 81]. At the same time, analyzing the non-verbal interaction between a presenter and his audience is frequently investigated in the field of learning and education [46, 75, 76], and *ConAn* facilitates this type of analysis by providing an export functionality, enabling the user to compare all aggregated features side by side.

In this case, the user can identify, for example, that while the ratio between being watched and looking at other people was almost equal (0.9) for the presenter in the video without devices, in the video with devices the ratio increased (1.4). In other words, in the scenario with listener devices the presenter made relatively fewer attempts to initiate eye contact with participants while being watched more in return.

6 DISCUSSION

As of today, we implemented all modality extractions and feature extractions using recent high-performing machine learning models. However, as all four domains – eye gaze, speaking activity, body pose, and facial action unit detection – are highly active areas of research, we are aware that the tool will have to be updated in the future. As this was clear from the beginning, *ConAn* has a modular extraction pipeline that allows replacing models and even add new features if they become valuable for conversation analysis in the future. This includes the possibility of making *ConAn* run in real-time when suitable algorithms become available.

The modular structure of *ConAn* also addressed the currently biggest challenge – the accuracy of the underlying extraction methods. While we use state-of-the-art machine learning models, they are not perfect yet. However, as we provide the first high-level tool on top of the latest algorithms, *ConAn* can already now drastically reduce the time investment into conversation analysis, especially for HCI researchers. Further, as we provide an easy to use GUI, *ConAn* also allows novices to conversation analysis to incorporate findings from social and behavioral science into their analyses.

Through our use cases, we highlighted the capabilities of *ConAn*. *ConAn* can help researchers in various areas, from psychological studies investigating non-verbal behavior in relation to autism spectrum disorder [80], social anxiety [84], or social phobia [9], over supporting human resources in analyzing group mood at work [12], or collective intelligence and group satisfaction [26], to investigating technology in social interactions [20, 72, 81, 89] or incorporating conversation analysis in fast, iterative design processes [58], as well as investigating the impact of non-verbal behavior on education and learning [1, 74, 75].

In contrast to other available conversation analysis tools, *ConAn* provides out-of-the-box visualizations on the group level, geared to enable insights into group dynamics at a glance. Notably, the scope of these tools varies too significantly for a quantitative comparison to yield meaningful results. Furthermore, *ConAn* is the first system that is built around the use of a 360° camera. This feature addresses one of the major challenges in group conversation analysis, i.e. the need for elaborate multi-sensor setups and the corresponding time-consuming synchronization and calibration task. Consequently, because of the portability and ease-of-use of a single 360° camera, with our tool, group conversations in any type of setting are now available for comprehensive non-verbal behavior analysis.

7 CONCLUSION AND FUTURE WORK

We presented *ConAn* – an open-source tool to perform conversation analysis using state-of-the-art machine learning models for feature extraction. *ConAn* is an easy to use tool that reduces the need for time-consuming video and audio annotation. Thus, this allows HCI researchers to quickly perform conversation analysis, for instance, during rapid prototyping to incorporate technology's impact already during design time. *ConAn* allows others to record a conversation using a single camera but retrieving a large number of features. For this, we use video and audio to extract the low-level modalities: eye gaze, speaking activity, body and hand pose, facial expressions, and information about the environment. The information-rich modalities can then be used to abstract high-level insights or even to compare multiple conversations.

In future work, we plan to conduct a user study to corroborate our findings by quantitative analysis of coder's time savings and overall user experience. In particular, we plan to compare the workflow and accuracy between our tool and manual annotations. Furthermore, it will be interesting to explore the usability of *ConAn* in extended use cases, such as video conferencing or videos with blurring for subject's privacy.

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