# New Methods of Operational Interviewing: Utilizing Non-contact Sensors

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## ABSTRACT

There is a critical need to conduct operational interviews in a wide range of interview and assessment situations, including conventional structured interviews as well as cases in which subjects are unconstrained. Current progress of three advanced prototype instrument development projects looking at non-contact sensing of human physiology to determine the veracity of human communications are presented. These include: 1) Thermal Facial Screening (TFS); 2) Turnkey Remote Assessment of Concealed Knowledge using Eye movement Recordings (TRACKER); and 3) Laser Doppler Vibrometry (LDV). Signals are measured with superior technical quality, in comparison to those obtained with conventional contact methods. Depending on the operational need and the specific context, these instruments can be used as stand-alone techniques or integrated into a multi-modal evaluation of human credibility. Thus, a comprehensive assessment using multiple physiological response systems is possible. A description each technique, the current state of these research efforts, and an overview of the potential for each of these emerging technologies will be provided.

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## THERMAL IMAGE ANALYSIS

***What is Thermal image Analysis?*** Thermal Image Analysis is a technique used for measuring radiant energy or natural heat (infrared) emission from the human body (Gorbach, 1993). Using infrared (IR) radiometry, heat measurements from large areas of the body surface can be made without skin contact. Skin surface temperature (SST) is affected by changes in underlying muscle activity and microcirculation. Increases in muscle activity result in increases in blood flow to the arterioles surrounding the muscle, and these changes are associated with a rise in heat production.

***What are the preliminary findings?*** Using high-definition, rapid response thermal imaging, real-time changes in skin surface temperature across the face were effectively recorded. Skin surface temperatures overlying muscles around the eyes and nose appeared to be the most effective predictors of deception, but only when combined with the traditional polygraph measures of respiration, cardiovascular, and electrodermal activity. The finding that dichotomous classifications based on a combination of SST and BV amplitudes significantly correlated with group membership also suggests that a combination of SST and traditional polygraph measures might lead to more effective means of detecting deception.

***What is the future for Thermal Image Analysis?*** There are still many questions that need to be answered before thermal image analysis can be used effectively in the field. We are still not sure how to effectively combine thermal data with traditional polygraph channels in a way that will be useful in “real time” by the operators. We are conducing basic research on the relationship between SST and other measures to develop a theory of the psychophysiological processes responsible for the effects seen. For example, the two sites most predictive of deception in the present study were SSTs measured in the periorbital regions around the eyes and the nose. At the present time, we are still unsure which psychophysiological processes are responsible for these changes. The following study is indicative of recent advancements in using Thermal Image Analysis.

# Lie Detection - Recovery of the Periorbital Signal through Tandem Tracking and Noise Suppression in Thermal Facial Video

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## ABSTRACT

Previous work has demonstrated the correlation of periorbital perfusion and stress levels in human beings. It has also been suggested that periorbital perfusion can be quantified through processing of thermal video. The idea has been based on the fact that skin temperature is heavily modulated by superficial blood perfusion. Proof of this concept was established for two different types of stress inducing experiments: startle and mock-crime polygraph interrogations. However, the polygraph interrogation scenarios were simplistic and highly constrained. In the present paper, we report results on a large and realistic mock-crime interrogation experiment. The interrogation is free flowing and no restrictions have been placed on the subjects. We propose a new methodology to compute the average periorbital temperature signal. The present approach addresses the deficiencies of the earlier methodology and is capable of coping with the challenges posed by the realistic setting. Specifically, it features a tandem condensation tracker to register the periorbital area in the context of a moving face. It operates on the raw temperature signal and tries to improve the information content by suppressing the noise level instead of amplifying the signal as a whole. Finally, a pattern recognition method classifies stressful (Deceptive) from non-stressful (Non-Deceptive) subjects based on a comparative measure between the interrogation signal (baseline) and portions thereof (transient response). The successful classification rate is 87.2% for 39 subjects. This is in par with the success rate achieved by highly trained psychophysiological experts and opens the way for automating lie detection in realistic settings.

**Keywords:** Thermography, Polygraph, Tracking, touchless monitoring

## 1 INTRODUCTION

Stress has long been associated with deceptive behavior during interrogation. It emanates from a brain center and manifests itself in the peripheral senses through a variety of physiological signatures, including perspiration, pulse, and breathing rate [4, 2]. Polygraph examinations are based exactly on this principle. However, polygraph technology is based on contact sensors and heuristic analysis of signals by experts [3]. As a result, the comfort of subjects is compromised, which is very important in psychophysiology, as it is believed to contaminate the experiment [4]. The analysis of the results is slow because it is performed manually by several experts who later have to reconcile their findings. The processing of a typical 10 minute interrogation session may take several hours. Finally, due to the heuristic nature of the analysis the outcome cannot be embraced with high confidence and always has a suggestive nature.

Traditionally, polygraph examination is used by the U.S. Government to check periodically the veracity of employees that hold security clearances. It is also favored in some instances by private companies for screening during the hiring process. This is primarily for potential employees who will assume sensitive positions. Due to the problems of the existing polygraph technology, polygraph examinations are inadmissible in court. In recent years and with the intensification of the war on terror, there has been a clear desire for improving or replacing the polygraph technology with something better. There is a real need for administering real-time, highly automated veracity tests inside the country and around the globe, where human intelligence is being collected. At the same time, similar technology may be useful for quick screening of potential suspects in ports of entry [5].

Pavlidis et al. have discovered a physiological signature on the face directly associated with stress levels [6]. Specifically, they demonstrated that during stress produced by startle stimuli in the lab, subjects exhibited elevated blood perfusion in the periorbital area, which resulted into localized elevated temperature. They further suggested that such a heat signature can be captured by a highly sensitive thermal imaging system and analyzed using pattern recognition methods. Based on this principle, they have later developed an imaging system for quantifying stress during polygraph examinations. The system was put into comparative test with traditional polygraphy in an experiment designed and prosecuted by the Department of Defense Polygraph Institute (DoD PI). The accuracy between the two modalities was found to be equivalent (around 80%), thereby establishing the feasibility of the idea [7].

The DoD PI experiment was small in scale (20 subjects) and highly contrived. Questions were posed to subjects multiple times and there where long pauses between each question. The subjects had to give a binary answer (‘yes/no’) to impose uniformity on the time scale [8]. The subjects were also instructed to stay as still as possible. This is quite apart from the natural interrogation scenario where there are no motion restrictions and the flow is continuous and non-uniform. Actually, the pace of the interrogation accelerates or decelerates at times to build up psychological pressure.

Recently, the Psychology Lab at Rutgers University in cooperation with the Infrared Imaging Group in the University of Houston designed and executed a large mock-crime experiment, where all the aforementioned restrictions during interrogations were removed. Facial thermal video along with audio was recorded for every subject. The analysis of the thermal imagery demonstrated the limitations of the earlier methodology proposed by the way of the DoD PI experiment. Then, the problem of signal fading was addressed through transformation from the temperature to the blood perfusion domain via bioheat modeling. This magnified the scale of the phenomenon but also amplified the noise levels.

In this paper, we propose an entirely different methodology, which addresses the issue of automatic deception detection under the most realistic conditions and for a statistically significant number of subjects. The only similarity between the present and the past approaches is that the periorbital region continues to be the region of interest.

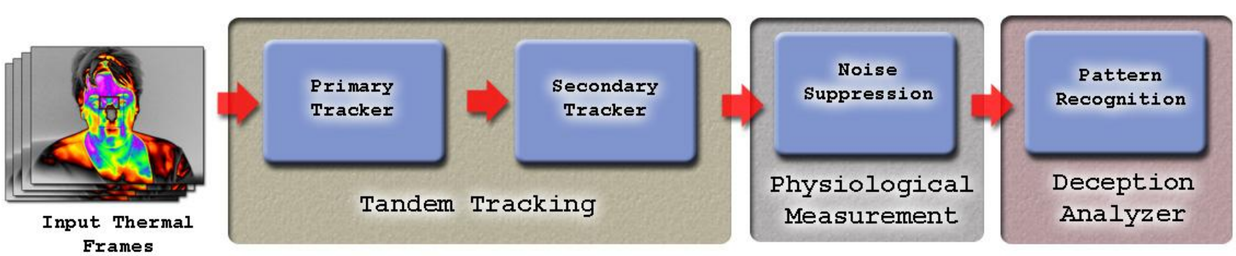

Fig. 1: System Architecture.

In section 2 we provide an overview of the experiment and the proposed imaging solution. In section 3 we describe the facial and periorbital tracking algorithm, which enables acquisition of temperatures from the tissue of interest despite head motion. In section 4 we describe the physiological measurement and our noise suppression methodology. In section 5 we present the pattern recognition algorithm that operates on the filtered temperature signal to perform the binary classification ('Deceptive' or 'Non-Deceptive'). In section 6 we discuss the experimental results and ponder the strong and weak points of our approach. We conclude the paper in section 7.

## 2 OVERVIEW OF OUR APPROACH

Our objective is to extract the average temperature signal in the periorbital area of the subject through the course of the interrogation. Fig. 1 depicts the system architecture that realizes this objective. Specifically, we have a specialized tissue tracker that registers the subject's periorbital region despite the presence of motion. The temperature signal output by the tracker is marred by noise. While some systemic noise from the electronics of the thermal imaging system is present, the major source of noise stems from imperfections in the tracker. Therefore, a noise reduction algorithm (filter) is necessary to improve the quality of the signal. Finally, we have a pattern recognition algorithm that compares the overall outlook of the filtered signal (baseline) versus specific instances of high psychophysiological value (transient response). This comparison constitutes the basis of a binary classification rule ('Deceptive' or 'Non-Deceptive').

## 3 TANDEM FACIAL TRACKING

Condensation tracking in various forms has proved effective both in the visible [9] and infrared spectra [9]. Tracking accuracy fluctuates because occasionally the method is fooled by a local extremum. If tracking is regained momentarily, then the effect in typical applications (e.g., surveillance) is minimal. However, in physiological monitoring applications such as ours, even temporary loss of tracking creates serious problems. It results in spikes in the temperature signal of the tracked tissue, which are falsely indicative of strong physiological responses. This may mislead the pattern recognition algorithm.

Tracking is most challenging for the periorbital region, since it is a small highly uniform tissue area and its projection is greatly affected by the pan and tilt angles of the head. Even when tracking is maintained, it typically drifts over time. To address this issue, we have introduced the novel concept of *tandem tracking*. Simultaneously with the periorbital region we track a central facial region that is rich in contrasting features (see Fig 2) and more invariant than the periorbital region to pan and tilt rotations. The quality of tracking for this central region is better on average and can be used to correct the estimate of the periorbital tracker.

The scheme works as follows:

1. The operator selects two rectangular regions on the initial frame of the thermal clip - the central facial and periorbital.
2. The two regions are tracked by two independent condensation trackers. The feedback measurement for each tracker is based on a regular grid template. In essence, this is a sub-sampling of the

rectangular region of interest. We have determined experimentally that a surprisingly small sub-sample of the original area produces the same tracking result as the full area.

3. The relative spatial position of the central and periorbital regions is established in the initial frame.
4. In subsequent frames the condensation trackers come up with independent position estimates. The position estimate of the central facial tracker is considered more reliable. Since the relative position of the periorbital region to the central facial region has been established in the initial frame, the position probability suggested by the central tracker for the periorbital region is weighted against the independent estimate of the periorbital tracker itself. The combined estimate provides for a robust solution and helps the periorbital tracker to overcome local extrema (see Fig 2).

## 4 PHYSIOLOGICAL MEASUREMENT AND NOISE SUPPRESSION

For every frame we compute the average temperature of the 10% hottest pixels from within the periorbital region of interest. We have found experimentally that this represents the average temperature on the vasculature in the inner corners of the eyes (see Fig 3). It is the periorbital region with the highest perfusion rate (that's why it is the hottest) and is minimally affected in the imagery by blinking. Therefore, assuming that tracking is accurate, it provides a temperature signal that is indicative of blood perfusion activity in the eye musculature. We consider that the periorbital temperature signal, as defined above, it consists of several components:

1. A low varying component indicative of the long term trend of perfusion levels, which is of high information value.
2. A mid frequency component, which is associated with temporary disturbances in blood perfusion caused by stress in specific Question and Answer (Q&A) sessions. This is also of high information value.

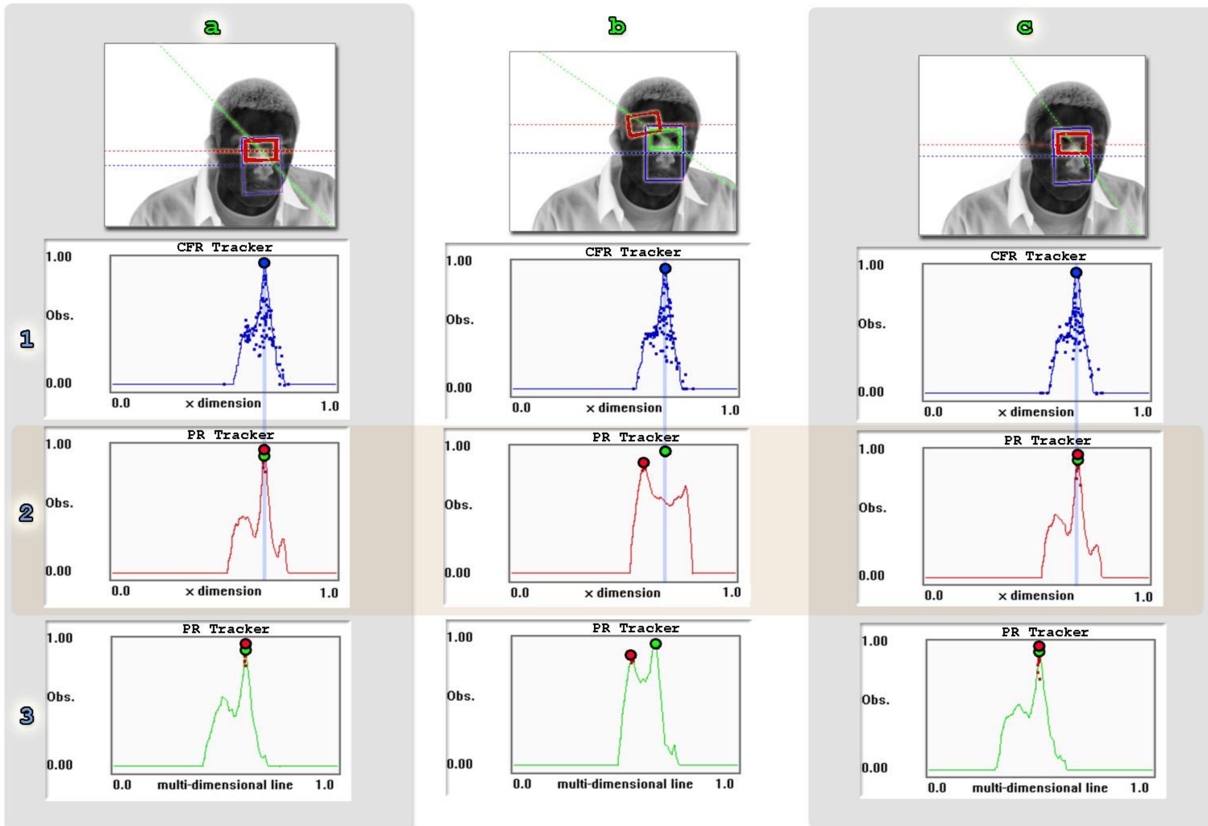


Fig 2. Tandem Facial Tracking. (a) Initial frame ($F$ = 1) where the central facial region selection appears in blue while the periorbital region selection in red. (b) Intermediate frame ($F$ = 330) that shows loss of tracking for the implementation of the periorbital region that is not tandem tracked. (c) Subsequent frame ($F$ = 343) that shows regain of tracking after tandem tracking is reconstituted. (1) Observation densities along the mid horizontal (dotted blue line) for the Central Facial Region (CFR) tracker. The solution is identified with a blue disk. The three graphs correspond to the three frames a, b, and c. (2) Observation densities along the mid horizontal dimension (dotted red line) for the Periorbital Region (PR) Tracker. The solution is identified with a red disk. The three graphs correspond to the three frames a, b, and c. The PR tracker was set to ignore the influence of the CFR tracker in frame b ($F$ = 330) and the result is temporary loss of tracking. (3) Observation densities along the green line crossing through the centers of the two PR regions in frame b. Since a parallel PR tracker without tandem influence is spawned only in frame b, this is the only instance that the respective PR regions are differentiated. One can observe that the non-tandem PR tracker selects a local maximum (red disk in graph 3b), which does not correspond to the global maximum caught by the tandem PR tracker (green disk in graph 3b).

3. A high frequency component caused primarily by tracker instability and systemic noise.
4. An impulse component caused by temporary tracking failures.

Our noise suppression effort is focused on eliminating the impulse and high frequency components.
We use a mean filtering method to remove the impulse noise. We define the average periorbital temperature signal as $T[n], 1 \le n \le N$, where $N$ is the number of frames in the thermal video clip. We compute the mean absolute inter-frame temperature difference as:

$$\overline{\Delta T} = \frac{1}{N-1}\sum_{i=2}^{i=N} |T[i]-T[i-1]| \quad (1)$$

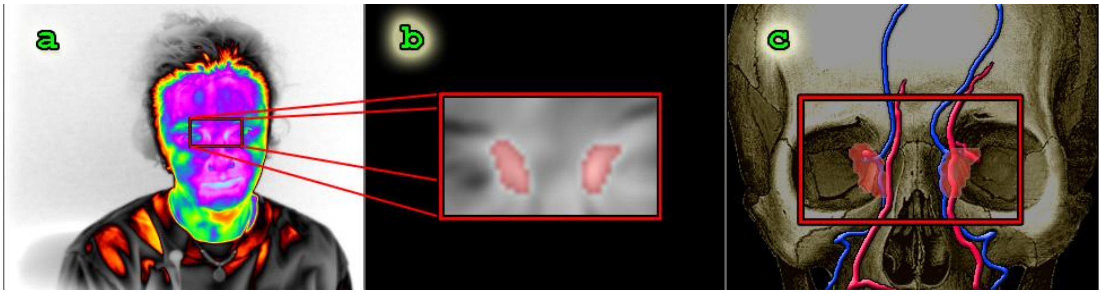


Fig 3: (a) Facial thermal frame of a subject with the periorbital region of interest superimposed. (b) Blow-up of the selected region of interest with the 10% hottest pixels marked in pink. (c) The periorbital region of interest with its 10% hottest subset superimposed on the facial and ophthalmic arteriovenous complex. The heat convected by the blood perfusion in this complex is responsible for the elevated temperature with respect to the rest of the periorbital region. Supply of additional blood to the eye muscle is realized through this complex. Therefore, monitoring the conduit in the eye corners is sufficient to detect the 'fight or flight' syndrome during stress.

We consider the signal value $T[i]$ as impulse noise (spike) if $|T[i]-T[i-1]|>\Delta T$. In this case, we replace $T[i]$ with the following interpolated value:

$$S[i]=\begin{cases} T[i-1]-\overline{\Delta T} & \text{if } T[i]<T[i-1], \\ T[i-1]+\overline{\Delta T} & \text{if } T[i]>T[i-1]. \end{cases} \tag{2}$$

The result of the impulse removing operation $f$ is a new signal $S[n]=f\left(T[n]\right), 1\le n\le N$ (see Fig 4). We remove the high frequency component of signal $S[n]$ through novel application of Fourier decomposition. Specifically we have the following algorithmic steps:

**Step 1:** We apply the Fast Fourier Transform (FFT) on signal $S[n]$ to get the power spectrum:

$$S(\omega)=F(S[n]). \tag{3}$$

The FFT method was first introduced by Cooley and Tukey [11]. Thereafter, it was used widely in signal analysis due to its high efficiency in comparison to other methods, such as the solution of linear equations or the correlation method [12]. To apply the FFT on the impulse filtered signal $S[n]$, first we use a low order trigonometric polynomial as follows [13]:

$$\begin{gathered} u[n]=s[n]=(\alpha\cos(n)+\beta), \\ \text{with } \alpha=\tfrac{1}{2}(s[0]-s[N-1]), \beta=\tfrac{1}{2}(s[0]+s[N-1]). \end{gathered} \tag{4}$$

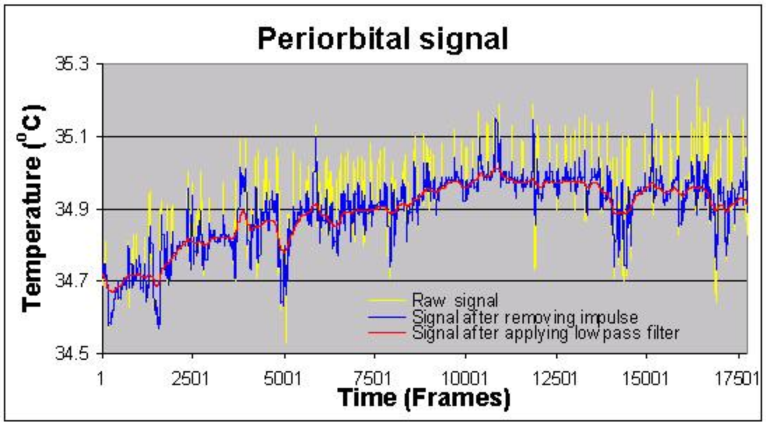


Fig 4: Periorbital temperature signal before (yellow) and after (blue) removing the impulse noise. The red curve shows the low-pass filtered signal after the application of the Fourier decomposition.

This ensures that the shift will not affect the stability of the scheme by minimizing the Gibbs phenomenon. Then, we extend $u[n]$ to a $2N$ periodic function as follows. First, we apply the symmetry [13]:

$$\forall n \in [0, N], u[N-n] = -u[n] \tag{5}$$

and second the periodic extension:

$$\forall n \in [0, 2N], \forall k \in \mathbf{Z}, u[n + k2N] = u[n] \tag{6}$$

We apply a classical decimation-in-time (Cooley and Tukey) 1D base-2 FFT method given in [14].

**Step 2:** We apply a low-pass filter on the power spectrum $S(\omega)$ to suppress high frequency noise. The filter is constructed using an exponential function:

$$H(e^{\omega 0.1}) = \sum_{n=0}^{\infty} u[n] - e^{\omega 0.1n}. \tag{7}$$

**Step 3:** We move back to the time domain by applying the inverse FFT on the filtered spectrum $S'(\omega)$:

$$\tilde{u}[n] = F^{-1} S'(\omega), \tag{8}$$

followed by re-normalization: $\tilde{s}[n] = \tilde{u}[n] + (\alpha \cos[n] + \beta)$. (9)

The low-pass filtered signal $\tilde{s}[n], 1 \le n \le N$ is fed to the pattern recognition module.

## 5 PATTERN RECOGNITION

We are interested in deriving a decision scheme, which will separate the Deceptive (D) from the Non-Deceptive (ND) subjects, based on the noise-cleaned temperature signals. Our previous research has indicated that elevated levels of stress are associated with elevated periorbital perfusion and temperatures [6, 7]. However, the degree of temperature elevation depends not only on the intensity of stress but also on the psycho-physiology of the subject. Different subjects react with different intensity to the same stress stimuli [8]. Therefore, an effective decision scheme has to normalize inter-individual variability through an intra-individual measure. We compute the slope $D_i$ of the filtered temperature signal $\tilde{s}[n]$ that corresponds to the entire length of the interrogation for each subject *i*. This represents the trend or baseline response of the subject to the experiment. We also compute the slope $d_{i4}$ of the portion of the signal that corresponds to the Q & A session with the highest *impact factor*. We define as impact factor, the level of perceived psychological stress a question has per unit time. In other words, for a question to have a high impact factor it is not only necessary to be 'tough,' but also short. It should also be preceded by a series of questions that slowly build pressure on a subject up to a culmination point. In our interrogation scheme, question 4 qualifies as such question. In the computation of $d_{i4}$ we consider the signal from the beginning of question 4 to the beginning of the respective answer. Per the psychophysiological theory [15] this is the interval of interest in a Q & A session.

Our decision scheme is based on the comparison of slope $d_{i4}$ with $D_i$ for subject *i*:

$$d_{i4} - D_i \rightarrow \begin{cases} > 0 \text{ subject } i \text{ is D,} \\ \leq 0 \text{ subject } i \text{ is ND.} \end{cases} \tag{10}$$

In other words, if the physiological change in the critical question is greater than the baseline change, then the subject is classified as deceptive. This binary classification rule can be relaxed by establishing a third 'indecision' class when $d_{i4} - D_i$ is very close to 0.

## 6 EXPERIMENTAL SETUP AND RESULTS

The experiment was designed by the Psychology Lab of Prof. M.G. Frank in Rutgers University. Subjects were a sub-sample of 39 (19 males, 21 females) taken randomly from a larger population of 150 developed by Frank & Ekman [16]. They were all members of politically active groups both on and off campus. The subjects responded to either face to face or e-mail enquiries to participate in a communication skills experiment. When they appeared in the laboratory, they were told that deception is a part of communication, and that is the skill under examination for this experiment. They then completed a number of demographic and personality inventories. Afterward, they were presented with their specific instructions for the deception situation. They were told that there was a check in an envelope hidden down the hall. This check was made out to a group that the subject adamantly opposed (e.g., prolife subject, check made out to pro-choice group, and vice versa). The subject was told to find the check, and then decide whether or not to 'steal' it. If they stole it, they were to put it in their pocket. Whether or not they took the check, they then returned to the experimenter. The subject was then interrogated by a person whom they believe belongs to (or is a strong supporter of) a group they oppose (e.g., the subject who is pro-life will be interrogated by a person whom they believe is pro-choice). This means that a subject who stole the check lied about it under interrogation. If they fooled the interrogator, they were able to tear up the check (thus depriving their hated group of money), and they obtained $75 for themselves and this $100 would go to their group instead. If they failed to convince the interrogator of their innocence (i.e., caught lying), the $100 check would go to the group that the subject despised, the subject and their group would get no money, and the subject must withstand 30 minutes of loud, startling blasts of noise delivered via headphones. If the subject did not take the money, and they were judged truthful, they received $25 for themselves and $25 for their group, and the despised group would not get $100 but a smaller sum instead. If the subject was mistakenly judged as lying, then neither they nor their group got any money, the despised group got less money, and the subject was to face the loud startling blasts of noise. Note that no subjects were actually punished with the loud startling blasts of noise and all received at least some money for participation. What was important was for subjects to feel there was a punishment for not being seen as truthful.

The interrogation questions were derived by a panel of homicide and counter-terrorism professionals in conjunction with behavioral scientists [16]. Two of the questions specifically tested the idea's around a popular interrogation technique called the Reid technique [15], whereas the others were designed to elicit maximum useful nonverbal behaviors. In particular, it was composed of the following questions:

1. Describe in detail everything you saw down the hall.
2. Describe your actions while you were down the hall.
3. What was going through your mind regarding whether to take or leave the check?
4. Did you remove the check from the envelope?
5. Is there anything else you wish to tell me about the check or what you did?
6. Is everything you have told me about the check the truth?
7. What would you say if later I determined you lied to me about the check?
8. Where did you put the check?
9. What should happen to a person who took a check like this?
10. Have you ever told a lie to get out of serious trouble?
11. I know who that check was made out to. It is very understandable that you would not want to see money going to that organization. If I were in your shoes, I probably would have done anything in my power to avoid having money go to this organization. Now tell me the truth, did you take that check or not?
12. If you were to take a polygraph (lie detector machine) test, what do you think the results of this test would be?
13. Why do you think that someone would take this check?

The experiments conducted through the course of 12 months in a standard room. Three different environmental conditions were realized through the course of the experiments, each spanning several months in duration. Initially, the subjects were illuminated with a strong photographic light, which was causing significant elevation of the facial temperature. The setting was simulating to a certain degree outdoor conditions, where the subject would have been exposed to the sun. This initial batch of subjects is marked as Tape I in Table 1. Midway in the course of the experiments the photographic light was removed and the room was heated (winter time) to a typical indoor temperature ($25^{o}C$) while the subjects were dressed moderately. This is marked as Tape II in Table 1. Towards the end of the experiment the room was maintained to a typical indoor temperature ($27^{o}C$) without heating (spring time) and the subjects were lightly dressed. This is marked as Tape III in Table 1.

Interrogations were recorded with the University of Houston specialized thermal imaging system along with a separate synchronized voice channel. The recorded thermal clips were processed per the methodology outlined in sections 3 - 5. The voice channel was used to delineate the interrogation and the critical question 4 intervals in the frame sequences. The decisions supported by our scheme were compared against the ground-truth released by the Psychology Lab of Prof. M.G. Frank. The detailed classification results are shown in

Table 1. The results clearly demonstrate the beneficial role of the impulse removal and lowpass filtering algorithms. It is also interesting to note that the method is more successful in detecting Deceptive (D) rather than Non-Deceptive (ND) subjects.

Based on the trend exhibited by the current experimental results, it is reasonable to expect that the performance of the method can improve simply by improving the accuracy of the tracking algorithm and the quality of the thermal imaging system.

## 7 CONCLUSIONS

We have presented a new methodology for recovering the periorbital signal from thermal facial sequences. It depends on tandem tracking and noise suppression. Tandem tracking ensures that the poorly featured periorbital region of interest is tracked accurately by weighing in feedback from the rich in features central facial region. Noise suppression removes spikes and high frequency components from the periorbital signal, which are due to tracking imperfections and electronic interference. The filtered signal is classified as Deceptive (D) or Non-Deceptive (ND) based on the slope differential between the entire curve and portions thereof (question 4 in our case). Subjects who exhibit higher change in critical moments with respect to their interrogation baseline are classified as D. Our method scored an 87.2% accurate prediction rate on 39 subjects interrogated by the Psychology Lab at Rutgers University per the designed mockcrime protocol. This is in par with the performance exhibited by seasoned interrogation experts.

This work follows up on the authors' previously reported methodology and results by the way of the DOD PI experiments [8]. This time the sample is double in size (39 versus 20 subjects) and the conditions quite realistic. The old method of amplifying the signal through transformation from the temperature to the blood flow domain was abandoned in favor of a noise suppression method. The periorbital region of interest has been more clearly defined as the inner corner of the eyes, where the facial and ophthalmic arteriovenous complex is supplying blood flow to the eye musculature. The importance of tissue tracking to cope with motor and fidgeting motion has been brought to the fore.

Our research further demonstrates the efficacy of automated lie detection by shedding more light into the associated physiological mechanism and coping with increasingly more realistic experiments. We are currently working on improving the performance of the tracking algorithm and computing the curve slopes through polynomial interpolation. At the same time we plan on processing more subjects to ensure that the method continues to scale up in larger data set.

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| | SubjectID | Ground-Truth | Original Signal | Impulse Filtered Signal | Lowpass Filtered Signal |
|---|---|---|---|---|---|
| TAPE I | S20 | D | 0 | 0 | 1 |
| | S21 | D | 0 | 0 | 1 |
| | S23 | D | 0 | 0 | 0 |
| | S24 | D | 0 | 0 | 1 |
| | S26 | D | 1 | 1 | 1 |
| | S27 | D | 1 | 1 | 1 |
| | S29 | D | 1 | 0 | 1 |
| | S31 | D | 1 | 1 | 1 |
| | S19 | ND | 1 | 1 | 1 |
| TAPE II | S57 | D | 1 | 1 | 0 |
| | S62 | D | 1 | 1 | 1 |
| | S63 | D | 0 | 1 | 1 |
| | S65 | D | 1 | 1 | 1 |
| | S68 | D | 0 | 0 | 1 |
| | S69 | D | 0 | 0 | 1 |
| | S75 | D | 0 | 1 | 1 |
| | S80 | D | 1 | 1 | 1 |
| | S81 | D | 0 | 0 | 1 |
| | S87 | D | 1 | 1 | 1 |
| | S88 | D | 1 | 1 | 1 |
| | S92 | D | 1 | 1 | 1 |
| | S49 | ND | 1 | 1 | 1 |
| | S52 | ND | 1 | 1 | 1 |
| | S58 | ND | 0 | 0 | 1 |
| | S73 | ND | 0 | 0 | 1 |
| | S76 | ND | 1 | 1 | 1 |
| | S86 | ND | 0 | 0 | 0 |
| | S91 | ND | 0 | 0 | 1 |
| TAPE III | S99 | D | 0 | 0 | 0 |
| | S104 | D | 1 | 1 | 1 |
| | S110 | D | 1 | 1 | 1 |
| | S165 | D | 0 | 0 | 1 |
| | S96 | ND | 1 | 1 | 1 |
| | S97 | ND | 1 | 1 | 1 |
| | S111 | ND | 1 | 1 | 1 |
| | S161 | ND | 0 | 0 | 0 |
| | S162 | ND | 0 | 1 | 1 |
| | S168 | ND | 1 | 1 | 1 |
| | S172 | ND | 1 | 1 | 1 |
| Overall Success Rate for D | | | 54.2% | 58.3% | 87.5% |
| Overall Success Rate for ND | | | 60.0% | 66.7% | 86.7% |
| Overall Success Rate | | | 56.4% | 61.5% | **87.2%** |

Table 1: Experimental Results. Successful prediction is marked as ‘1’, while unsuccessful prediction as ‘0’.

# THE PHYSIOLOGY OF THREAT: REMOTE ASSESSMENT USING LASER DOPPLER VIBROMETRY

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***Introduction.*** The overall goal of this project is in keeping with the desirability of assessing physiological activity remotely, without encumbering, constraining or interfering with the natural expression of emotion and stress. The work described here is based on the method of Laser Doppler Vibrometry (LDV). Using the LDV method, the contact with the subject is limited to exposing the skin to a low power laser beam. As we describe below, the LDV method is capable of assessing the responses in a number of important physiological response systems. In some cases, the measures are technically superior to those obtained using more conventional (and sometimes quite invasive) methods. Data can be obtained very quickly (usually in just a few seconds), and at distances of at least five meters (and probably much greater distances). As such, the LDV method may confer significant advantages not only in structured assessment situations, such as the polygraph examination, but also in less constrained circumstances such as interviews at checkpoints or interrogations.

***Laser Doppler Vibrometry.*** LDV is a technically mature method that is widely used in manufacturing and engineering processes, for non-destructive testing of mechanical structures. The instrument employs the Doppler principle to detect motion along the axis of the laser beam. By quantifying the interference patterns associated with the reflected and reference beams (with the reference beam shifted in frequency using a Bragg cell), direction-encoded movement can be detected. The principal manufacturer world wide is Polytec, who produced the instruments we are using in our project. Current generation LDV equipment is remarkable for the sensitivity with which extremely tiny movements can be detected, with a displacement threshold approaching 1 picometer. To place this in a biological perspective, the LDV displacement sensitivity is about 100,000 greater than the diameter of a typical virus, which is on the order of 100 nanometers.

The instruments we use (Polytec PSV-300, PSV-400, PDV-100) are of low power, between 0.6 and 1.0 mW output, and designated “eye safe” (i.e., Class II) by ANSI standards. The LDV instrument is generally lower in power than typical laser pointers, which range in power up to 5 mW (and sometimes more). Class II devices do not carry risk of ionization or thermal damage to the skin, and are considered eye safe so long as exposure is not continuous. The normal blink aversion response provides adequate protection. Nevertheless, the issue of eye safety is one that we are very sensitive to in our studies, and one that will need to be considered in any operational deployment of the LDV method. As we describe below, there are useful recording sites distant from the eyes, so in practice the risk of even momentary eye exposure can be reduced to a very low level.

***Laser Doppler Vibrometry as a physiological recording method***. There have heretofore been only limited attempts to study physiological activity (principally of the middle ear structures). and none to our knowledge targeting the physiological systems engaged during periods of stress and emotion. The underlying premise for the use of LDV in this context is that a major share of physiological activities have mechanical components, and that these components can be detected (however minutely) at the skin. This is certainly not a novel premise; indeed, it underlies many laboratory methods (such as accelerometry or plethysmography), as well as clinical methods based on palpation and auscultation. The sensing of body pulses and sounds was among the earliest clinical methods, and continues to play a significant role in the clinical examination. Since a great many physiological processes have some mechanical component, it follows that many different forms of activity could be sensed using the LDV—and indeed, as we describe below, the method can sense a variety of cardiorespiratory, tremor and muscle activities.

***The physiology of stress and emotion***. At the heart of forensic psychophysiology (and related applications) is the premise that the relevant of states of guilt, fear or threat are associated with patterns of physiological activation. Although early claims for a unique physiological "lie response" have been discredited, there *does* appear to be a fair amount of specificity inherent in the pattern of physiological responses. An important research thread dating back to pioneering work in the early 1950's, and now developing at an accelerating pace, shows that emotions and stress states can be differentiated on this basis. The overall thrust of these developments is that it is now possible to make much more specific statements, beyond global or unidimensional activation levels. As examples, affective valence (positive versus negative) has effects that can be distinguished from arousal level. Different kinds of stressors (e.g. social stressors versus cognitive stressors) are associated with distinctive response profiles, and the patterning of myocardial and vascular adjustments can serve as a basis for distinguishing whether an individual is *challenged* or t*hreatened* in the face of a given stressor.

Key to these distinctions, however, is the acquisition of data in multiple physiological response systems, or multidimensional observations within a given system, so that there is a basis for identifying distinctive response profiles. This is an area where, we believe, the LDV method has especial promise, as it is capable of assessing a number of key forms of physiological activity, in multiple response systems.

***Laser Doppler Vibrometry measures of cardiovascular activity.*** Major emphasis in our studies to date has been placed on validating the LDV signals within context of information obtained using conventional methods (including impedance cardiograph, electrocardiogram, photoplethysmograph, ballistocardiograph and beat-to-beat blood pressure recordings). In addition to the gross ballistic movements associated with the beating of the heart, there are many more specific forms of pulsatile activity that can be sensed throughout the body. The heart beat can be readily palpated at multiple chest sites, especially over the apex. There have been a number of clinical methods developed to quantify these movements (including *kinetocardiography* and *cardiokymography*) which, although never having entered routine clinical practice, have left a very substantial literature regarding the form and functional significance of the movements of the precordial wall. The LDV records generally agree quite well with published records based on these other methods, in disclosing a complex waveform that encodes mechanical aspects of pre-ejection, ejection and refilling phases of the cardiac cycle.

Consistent with our emphasis on developing methods that will be useful during unconstrained interviews, we have focused primarily on skin sites on the head and neck that would be freely accessible in most individuals, without requiring that clothing be rearranged or that the examinee assume a standardized recording position. The carotid artery site is a particularly rich site of information. The LDV waveform agrees well with published illustrations of pressure sensed much more invasively using indwelling manometers. The close relationship between the LDV signal and the blood pressure waveform is consistent with empirical findings that arterial vessel diameter is closely related to internal pressure. The LDV carotid pulse contour is richly textured, showing clear inflection points associated the upstroke and incisura, as well as additional features disclosing pressure wave reflections. Although much remains to be done in terms of understanding the functional significance of all of the features of the LDV carotid pulse, they do provide clear measures not only of heart rate but also more advanced aspects relating to systolic time intervals, ejection velocity, pulse wave velocity and peripheral resistance. Moreover, the LDV signals are generally of sufficient quality to support analysis on a beat-to-beat basis, allowing for detection of transient changes as would likely occur during an interview. We should also note that we can obtain high quality pulse data from additional sites on the head and neck. One very promising site is over the superficial temporal artery, recorded just below the ear, where the signal is somewhat smaller than recorded from the carotid (typically 30-50% amplitude) but nevertheless quite usable. This site has the advantage of offering a targeting vantage that would be lateral and to the rear, and out of the examinee's field of view.

***Laser Doppler Vibrometry recordings of respiration.*** The chest wall can be seen by the unassisted eye to heave during respiration, so it is not surprising that a high quality LDV record of respiration can be obtained from the chest. The record agrees well with the record of respiratory effort obtained conventionally using a belt around the abdomen. We also can obtain a record of respiration from the carotid site, although this is much smaller and out of phase with the abdominal signal (reflecting perhaps negative pressure there during inspiration). An additional LDV measure of respiration can be obtained from the analysis of activity in a higher frequency band (ca 100-300 Hz) which includes energy relating to breathing sounds.

***Laser Doppler Vibrometry recordings of muscle tension.*** Muscle tension is of general interest as a sign of anxiety (among other psychological factors), but is of particular interest in this context because of the patterns of tension in the facial muscles, and their relationship with stress and emotion. The LDV method can detect the gross motions associated with surface deformation of the face, but can also detect much more subtle, and potentially more informative, aspects in the form of muscle vibrations (variously called "mechanomyogram" [MMG], or "acoustic myogram"). These low frequency vibrations are audible to the unassisted ear under special circumstances, or can be detected with the aid of a stethoscope or electronic amplification. The basis for the MMG is not completely understood, but there are three likely candidate (non-exclusive) mechanisms. All interpretations posit that the vibrations arise from the firing of individual motor units. According to one interpretation, the vibrations arise from the lateral expansion of the muscle belly (which remains isovolumic during contraction and therefore expands laterally as the muscle bundle shortens). A second interpretation is that there may be lateral vibrations of the entire bundle, arising from cylindrical asymmetries about the longitudinal axis. An additional contributing factor may arise in the form of changes in the angle of pennation during contraction. There is strong evidence that the MMG provides unique information, beyond what is represented in the conventional EMG. It is more veridically related to force production, over moderate levels of force, and it is sensitive to muscle composition as well as to neuromuscular disease processes.

In a series of initial validation studies with a small hand muscle (the first dorsal interosseous) under varying conditions of elastic and mass loading, we determined that the LDV method captures a high quality MMG signal. The spectrograms of the LDV MMG signals showed multiple peaks within the band of about 5-50 Hz, the amplitudes of which were systematically related to force production. In general, the LDV MMG performed as well as more conventional methods (including microphone and accelerometer recordings, as well as the electromyogram) in assessing the dynamics of muscle contraction. We also determined in these studies that LDV measures of finger tremor agreed almost perfectly with recordings based on conventional accelerometry.

More recently we have turned our studies to the muscles of the face, under conditions of posed facial expressions. In agreement with electromyographic studies, we find that the LDV MMG signal shows differential activation during posed facial expressions. For example, during a posed frown the activity from the muscles involved in lowering the brow (*corrugator*) are active, whereas those that produce a smile (*zygomatic*) remain silent. The converse applies when a smile is posed. Using the mapping capabilities of the scanning LDV instrument, we have determined that the spatial pattern of MMG amplitude agrees well with the anatomical placement of the muscles involved, for a variety of upper and lower facial movements. Of special interest, we have also determined that the LDV method is capable of detecting muscle activation even under conditions in which the tension is not sufficient to produce visible changes of facial expression. This was confirmed in a study of the muscles involved in raising the upper lip—an action commonly associated with the emotion of disgust. LDV MMG signals were reliably detected in the muscles responsible for this action (the *levator labii*) even under conditions in which examinees were instructed simply to imagine a disgusting odor. A crucial next step in our studies will be to investigate the patterns of facial MMG signals during the natural expression of stress and emotion, during interviews and other laboratory induction procedures.

***Laser Doppler Vibrometry assessment of voice.*** Since the production of speech entails significant physiological vibration activities, the voice signal is readily recorded using the LDV method. As is true of all LDV signals, the LDV voice signal is unaffected by ambient acoustic noise (as would be expected given the large acoustic impedance mismatch between air and skin). We have confirmed this empirically by recording high quality LDV voice and cardiorespiratory signals in noisy environments, including the extremely harsh environment of the magnetic resonance scanner.

***Laser Doppler Vibrometry assessment during interviews.*** We are, as yet, fairly early in the process of investigating the LDV signals during actual interviews or interrogations. In one experiment, we obtained data from the carotid artery site during interrogations, in a laboratory paradigm in which subjects were given the option of stealing a check. The protocol involved a pay-off matrix that favored theft of the check and successful deception during a subsequent interrogation. We were successful in obtaining useful carotid pulse data in all subjects, from a substantial portion of the available beats. The data revealed substantial differences, across individuals, in the magnitude of changes during the interrogation, in heart rate and left ventricular ejection time. There were additional changes in pulse contour in some examinees, consistent with changes in ejection force as well as arterial stiffening.

While this experiment successfully demonstrated proof of concept with respect to the utility of the LDV method during interviews, there are a number of remaining technical challenges:

1) In order to accommodate the natural range of examinee movement during unconstrained recording conditions, the LDV system must be capable of dynamically tracking the target site on the neck or head. We have developed, and are currently employing, a 2D system based on a template matching approach. This is generally effective, although there are occasional periods of signal loss if the movements are large or sudden. The next generation tracking system, currently under development, will employ a 3D (stereo) camera and active face modeling, to provide real time estimates of face pose as well as position.

2) There are a number of challenges still with respect to developing and implementing optimal signal processing methods. The principal source of noise in the LDV signal is the artifact associated with gross movements (as are seen, for example, during active speech or while nodding the head). There are several strategies for dealing with this artifact, the simplest of which is to identify those segments affected (the movements are often brief) and exclude them from data analysis. A more effective approach, which we are actively pursuing, is one in which models of the signals are developed (in terms of wavelet basis waveforms or other templates), and these are used as a basis for “denoising” the waveform.

***Summary.*** The findings reviewed briefly above support, we believe, the overall conclusion that the LDV method offers exceptional capabilities as a method for recording physiological signs of stress and emotion.

We have shown that the method can successfully record in several key physiological response systems, including cardiovascular, respiratory, tremor, voice and muscle tension activity. Our studies have confirmed that the method is useful during interviews and interrogations, even in its present state of development. Additional planned research and method development will, we anticipate, increase the sensitivity and operational flexibility of the method.

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**Eye Movement-based Memory Assessment (EMMA)**

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Polygraph techniques determine veracity by monitoring changes in physiological measures of autonomic nervous system (ANS) functioning in response to questions presented during a structured examination process. The psychophysiologic basis of polygraphy hypothesizes that individuals in deceptive situations experience an emotional response that causes arousal of the sympathetic and parasympathetic branches of the ANS. This increase in arousal can then be detected through measurement of physiological functions such as respiration, blood pressure, heart rate, and skin conductance. This approach claims a high degree of validity and reliability, and is the accepted standard of deception detection (Abrams, 1989).

Polygraphy successfully demonstrates that changes in physiological processes as a result of emotional arousal can provide information relating to prior knowledge. It follows that change in the responses of other processes, such as cognition and perception, could be measured and potentially employed in a similar manner. Since cognitive and perceptual processes are not directly affected by ANS arousal, a different underlying paradigm is required. Rather than focus on the emotional consequences of deceptive behavior, this approach examines the changes in elements indicative of cognition and perception.

Numerous studies have shown that previous exposure to materials can be revealed indirectly by changes in subsequent cognitive processing (e.g., Roedger, 1990; Schacter, 1987). Specifically, indirect measures of performance, such as speed and accuracy, show an increased efficacy in the processing of previously presented materials. These changes are taken to reflect a change in the way these materials are processed cognitively when viewed more than once. Recently, a new indirect measure of memory based on eye movement monitoring, developed at the University of Illinois, has been shown to effectively discriminate processing of novel versus repeated items (Althoff, 1998; Althoff & Cohen, 1999; Althoff et al., 1998). This eye movement-based memory effect indicates that previously seen items have fewer eye fixations to fewer regions in a scene, and lower levels of statistical dependency in the patterns of eye movement transitions between regions.

While some measures of ocular behavior, such as pupil dilation and blink rate, have been employed as measures of autonomic arousal (Hess, 1972), the measurement of eye movements has been used primarily to characterize the nature of information processing and how that processing is affected by experience (Cohen & Eichenbaum, 1993). Four characteristics of the eye movement-based memory effect have been identified (Althoff, 1998):

- Discrimination between repeated and novel stimuli
- Generalization across different experimental tasks
- Increase in effect size with increasing amounts of prior exposure
- Independence of explicit remembering of items.

TRACKER (Turnkey Remote Assessment of Concealed Knowledge using Eye movement Recording) is a standalone system based on the EMMA paradigm to support field users in determining an individual's prior knowledge of visual stimuli, including faces, objects and scenes. TRACKER supports the collection and analysis of fixation-based eye movement data for use in the determination of prior knowledge. The program supports the measurement and calculation of variables from eye movement data and performs an analysis on those data to determine if a subject has prior knowledge of a set of images. Analyses of the resulting measures successfully differentiate between novel and previously seen items at levels of over 88% (Cohen et al., 1996). This effect has been replicated in prototype field settings across different stimulus types and subject populations (Marchak, 1998a, 1998b, 1998c).

From the viewpoint of application to deception detection, eye movement-based methods hold promise on a number of dimensions. The eye movement response occurs automatically as an obligatory effect of prior processing experience. Since this effect occurs independently of consciously mediated activity on the part of the examinee, this methodology should be resistant to countermeasures. Further, unlike other indirect measures of memory, eye movement measures can provide specific information regarding the source of information that elicited the response (Althoff, 1998).


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