**Real-Time Arousal Detection Using   
Galvanic Skin Response Asset  
(Design Document)**

**Abstract**

The asset detects in real time human arousal based on measuring Electro-Dermal Activity (EDA), also known as skin conductance, galvanic skin response (GSR), electrodermal response (EDR), skin conductance response (SCR), and skin conductance level (SCL). EDA is measured from particular player in order to produce real-time signal features such as mean tonic and phasic activity level, rise time, recovery time, and slope of tonic activity. The asset will receive a filtered raw signal from a simple, low cost biofeedback device allowing sampling rate up to 0,8Khz. For operating the component, no calibration period is required. The results will be communicated from client or server side in order to be used for game adaptation. The level of arousal may be useful for emotion detection and for adaptation purpose, therefore the asset can be combined with the T2.3 Real-time Emotion Detection Asset and the T3.4 Player-centric rule- and pattern-based adaptation asset.

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**Description**

**Introduction**

Galvanic Skin Response (GSR), also referred to Electro-Dermal Activity (EDA), Skin Conductance Response (SCR), Psycho-Galvanic Reflex (PGR), or Skin Conductance Level (SCL), is related to the activity of the sweat glands, which are regulated by the sympathetic nervous system (Boucsein, 2006). When being open and functioning intensively, they emit water solution (sweat) which creates channels of higher conductivity toward the deeper skin layers (Andreassi, 2007). EDA represents the electrical conductivity of the skin, which is directly dependent on the activity of the sweat glands, and is often used to index the autonomic arousal (Bach et al., 2010). Besides its easy measuring, EDA is less ambiguous than facial muscles’ activity and heart rate (Kivikangas et al., 2011). As a disadvantage of EDA, it should be mentioned that possible external factors may change the humidity of the skin, and thus its electrical conductivity, which can lead to inconsistent results. EDA is influenced both by the values of temperature and humidity of the environment and the intake of food and refreshing drinks (Pflanzer and McMullen, 2015). On the other hand, it must be taken into account that the reaction of EDA is not instantaneous and delays relative to the stimulus of 1 to 3 seconds.

GSR offers a popular and affordable way for detection of player’s arousal in adaptive digital games and other affective computing applications. It can be applied together with emotions recognized using face expression, as far as arousal is not reliably shown on the face - face muscles may not map to emotional state in gameplay, autism, and other contexts (Picard, 2011)). Higher arousal occurring at external events with increased involvement of the subject causes a relatively rapid fall in skin resistance, with time offset of 1-3 seconds (Braithwaite et al., 2015). On the other hand, reduced arousal such as occurring in withdrawal and entering a relaxation period provokes a gradual rise in skin resistance. Thus, EDA indexes autonomic emotional and cognitive activities. Though skin conductance varies between subject (Schwartz, 1995), its higher and lower values correlate directly with stress and relaxation, respectively. Skin resistence values below 5 kOhm (kiloohms), i.e. skin conductance higher than 200 µS (microsiemens) or 2.3 in log scale, indicate a high level of brain arousal states such as high anxiety or concentrated introspection. At the other hand, skin resistence values higher than 25 kOhm, i.e. skin conductance lower than 40 µS or 1.6 in log scale indicate low arousal states like limited self awareness, boredom, or apathy (Shepherd, 2001).

The EDA is an umbrella complex presenting autonomic changes in the electrical skin properties and contains two types of components: background tonic Skin Conductance Level (SCL) reflecting general long-lasting (tens of seconds to tens of minutes) changes in autonomic arousal and phasic changes known as Skin Conductance Response (SCR) produced by sympathetic neuronal activity. SCL during periods lacking external stimuli forms the baseline. Thus, SCR indicates rather higher variability of the EDA signal due to short phasic localized fluctuations in arousal (Boucsein, 2012). This variability is modulated at higher frequency over the slower drifting signal of SCL reflecting slower changes of general level of arousal over a longer time interval (Figner & Murphy, 2010). That´s why simply averaging across the whole signal is a feature not sufficient for determination of the arousal.

SCRs have several important features: frequency (number of SCR’s detected in a specific time window); amplitude (maximal height of a single response); latency (offset time from stimulus onset to response onset); rise time (time from the response onset a to its maximum height); and ½ recovery time (time for recovering either 50% or 63% of the amplitude (Bouscein, 2012).

SCRs can be either spontaneous or so called non-specific (NS-SCR) occurring in absence of any identifiable discrete environmental events, or event-related (ER-SCR) produced as reactions to such external stimuli (Dawson et al., 2007). Both frequency of amplitude of NS-SCRs peaks (varying from 1-3 per minute at full relaxation and over 20 in high arousal states) are used as measures of background tonic skin conductance (Boucsein, 2006). However, during high arousal events, many of SCRs peaks may overlap and appear in close succession to each other, therefore requiring use of other methods for quantification of the actual number of NS-SCRs. Overlapping SCRs can be separated using Continuous Decomposition Analysis following a deconvolution separation approach (Benedek & Kaernbach, 2010) resulting in presentation of predominantly distinct and compact impulses appearing for less than 2 seconds. Another approach for estimation of SCRs relies simply on calculating area under the curve bounded by the filtered SCR signal and the abscissa representing a zero baseline (Bach et al., 2010), presenting a time-integral of the signal proportional to both the frequency and amplitude of sudomotor bursts. Thus, the integration of SCR value for the time window resulting in an indicator of integrated skin conductance response (ISCR) measured in μS\*s (Figner & Murphy, 2010).

Frequency of amplitude of NS-SCRs peaks are used together with the normalized tonic level (after substracting the baseline from SCL). Detection of the baseline implies a calibration period for baseline measurement which should be no less than a minute and might last up to 4 minutes (Braithwaite et al., 2015). Another normalisation could be applying log function over the amplitudes and peak numbers[[1]](#footnote-2), in order to decrease skewness (Dawson et al., 2000), while standartisation methods eliminate individual differences by applying either range corrected scores such as (SCL-SCLmin)/(SCLmax-SCLmin) using individual maximum and minimum values (Dawson et al., 2007) or SCR/SCRmax, where SCRmax is the participants maximum SCR (Braithwaite et al., 2015). As well, the area bounded by the SCR curve measure (in µS\*s) is standardized per time by dividing it by the length of the time window, which results in measurement in µS.

**Asset functionalities**

The asset produces two main metrics featuring user arousal based on the EDA signal, namely:

* Current level of user arousal measured in N levels, i.e. from 0 to N-1, where N is user-defined and has a default value (shown by the moving average[[2]](#footnote-3) of the GSR signal within the time window and using a sampling rate chosen by the asset user). The user arousal level is determined after a calibration period (CP) used to determined how minimum and maximum values of the EDA parameters of the individual differs from their correspondent values calculated by statistical analysis of human EDA signals. In case of lack of CP, the accuracy is based on average max and min signal features values of statistically significant data. Thus, calibration period is not required but is desirable for starting calculation of user arousal level. With collecting more data from given user, the asset starts providing more accurate data[[3]](#footnote-4).
* Current direction of eventual change of user arousal - increasing, decreasing or no changing (determined by the first derivative of the moving average of the GSR signal within the chosen time window and at chosen sampling rate).
* Current dynamic of eventual user arousal change – i.e. if the change is accelerating or fading (determined by the second derivative of the moving average of the GSR signal)

The level of arousal will be determined on a scale from zero up to maximum arousal level set by the asset user. This may be useful for emotion detection and for adaptation purposes, therefore the asset can be combined with the T2.3 Real-time Emotion Detection Asset and the T3.4 Player-centric rule- and pattern-based adaptation asset.

Prior to analysis, skin conductance is measured by a custom device with programmable sampling rate from 8 up to 800 Hz and down-sampled to 1 up to 100 Hz sampling rate in order to reduce possible noise. The asset will be able to produce real-time features of EDA signal measured from particular player for a time windows (with default duration 10s) at chosen sampling rate (default rate is 8Hz) after the end of a possible calibration period (at least two minutes), namely:

* phasic arousal level (from 0 to N-1, where N is set by the client and has default value of 3) - SCRAchievedArousalLevel
* tonic arousal level (from 0 to N-1, where N is set by the client and has default value of 3) – SCLAchievedArousalLevel
* moving average of the raw EDA signal
* phasic activity represented by:
  + amplitude of skin conductance response (micro-siemens):
    - minimum – SCRAmpl.MIN
    - maximum – SCRAmpl.MAX
    - mean – SCRAmpl.MEAN
    - SD – SCRAmpl.SD
  + SCR rise time SCRRise (in ms):
    - minimum – SCRRise.MIN
    - maximum – SCRRise.MAX
    - mean – SCRRise.MEAN
    - SD – SCRRise.SD
  + SCR ½ recovery time SCRRecoveryTime (in ms):
    - minimum – SCRRecoveryTime.MIN
    - maximum – SCRRecoveryTime.MAX
    - mean – SCRRecoveryTime.MEAN
    - SD - SCRRecoveryTime.SD
  + average rate of phasic activity for the time window (response peaks/second) – SCR.Count
  + average area (integral) under the phasic line per second - SCRArousalArea

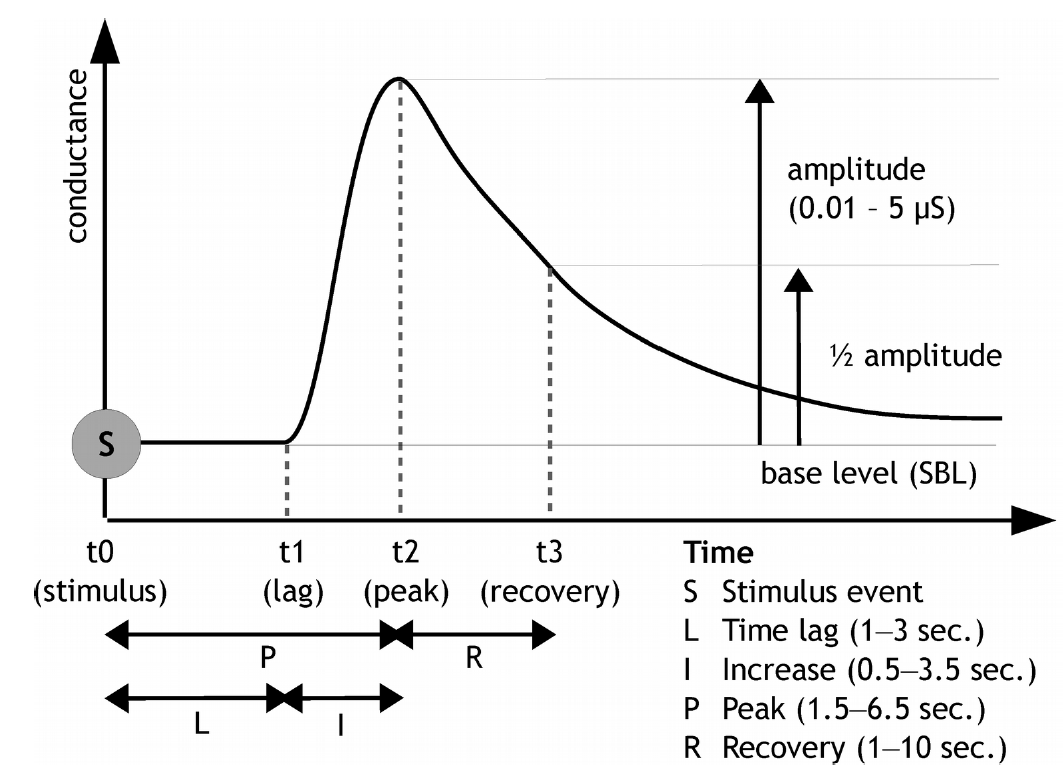


Fig. 1: EDA Response (SCR) pattern and relevant parameters (Leiner et al., 2012)

* phasic activity represented by:
  + slope of tonic activity (tangens of the slope angle of the tonic signal) - SCLSlope
  + amplitude of skin conductance level SCLAmpl (micro-siemens):
    - minimum – SCLAmpl.MIN
    - maximum – SCLAmpl.MAX
    - mean – SCLAmpl.MEAN
    - SD – SCLAmpl.SD

**Measurement process**

For a correct use of the asset, after asset startup there should be established a calibration period of minimum two minutes while the user is in total rest and not engaged in any given task. In a study of adaptive affective game, calibration periods were found to vary between 20s and 10 min (Bontchev, 2016). NOTE: if calibration period is not set, than population average values of the EDA parameter will be used (thus, implying the error will be the standard error for the population). The calibration period is used for measuring the SCL baseline, which will be subtracted from the SCL level for normalizing it. The baseline determined during the calibration period implying total rest of the user sets the zero tonic arousal level. In the same way, the zero phasic arousal level is set by the SCR features measured during the calibration period (total number of SCRs, average amplitude of SCRs, average rise time, average recovery half time, and total ISCR). On the other hand, average values of minimum and maximum of SCL and SCR features were registered during the experiments with a sample of decades of people (named as SCLmin, SCLmax, SCRmin, and SCRmax, where SCL and SCR denote tonic and phasic feature, respectively). These average values of minimum and maximum determine average values of minimum and maximum of both tonic and phasic arousal of the sample, i.e. estimation of the minimum and maximum of both tonic and phasic arousal of the population, in order to be used to carry out a linear interpolation on the signal. Therefore, the maximal level of tonic arousal will have a SCL value less than SCLmax, and the maximal level of phasic arousal will have a SCR feature value less than SCRmax for the same feature. For setting the maximal arousal value for given user having SCLcalibrate baseline and SCRcalibrate features measured during the calibration period, we correct the maximum EDA values by the coefficients SCLcalibrate/SCLmin and SCRcalibrate/SCRmin, with respect to the strong inter-subject variability and the linear relationship of EDA signal with sudomotor nerve activitity indicating arousal (Bach et al., 2010). Therefore, for a given user we estimate:

* Zero level of tonic and phasic arousal at SCLcalibrate and SCRcalibrate, respectively (in case of lack of calibration period we use mean values of SCLmin and SCRmin for the population);
* Maximal level of tonic and phasic arousal at SCLmax \* (SCLcalibrate / SCLmin) and SCRmax \* (SCRcalibrate / SCRmin), respectively (in case of lack of calibration period we use mean values of SCLmax and SCRmax for the population).

The asset uses a simple algorithm for calculation of both the phasic and tonic arousal level achieved by an individual for the preset time window (default time window is 10 s), as follows:

1. Preparation work – selection, informed consent signing, putting the sensors on palmar surface of the fingers of the non-dominant hand, startup of the asset, possible setup of time window (if different than default value of 10s), sampling rate (if different than default value of 400Hz down sampled 8 times), start of EDA measuring.
2. Calibration period (for 2 min at least) - user is relaxing and looking at relaxing video/hearing relaxing music.
3. End of the calibration period (CP) – the client program send a message to the asset (or calls its method endOfCalibrationPeriod()) for informing it about that end. This is required, because CP has no fixed duration. In that moment, the asset checks if the measured calibration parameters (Pcalibration) are lower of higher than the average for the population minimum values of these parameters (Pmin\_mean). Here, P = {SCLAmpl, SCLSlope, SCRAmpl, SCRRise, SCRRecoveryTime, SCR.Count, SCRArousalArea}. If so, the relation Ratio = Pcalibration/Pmin\_mean will be used for scaling the existing parameter range [Pmin\_mean, Pmax\_mean], i.e. calculation of arousal will be in the interval [Pmin\_mean \* Ratio, Pmax\_mean \* Ratio]:
4. The client code may set now:
   1. Time window (different than the default value of 10s)
   2. Levels of arousal (different than the default value of 3)
5. The client code may call now the method for returning all EDA tonic and phasic data plus the levels of tonic and phasic arousal:
   1. SCLSlope and SCLAmpl.\*;
   2. SCRAmpl.\*, SCRRise.\*, SCRRecoveryTime.\*, SCR.Count, SCRArousalArea;
   3. SCRAchievedArousalLevel, SCLAchievedArousalLevel.

At each call to the method, the asset updates the min and max values of the parameters for that individual, i.e. does support of min and max values of the user EDA for the measured subject.

1. The client code may call now the method for returning only the level of tonic or phasic arousal, i.e. SCRAchievedArousalLevel or SCLAchievedArousalLevel. The interval between SCLcalibrate and SCLmax \* SCLcalibrate / SCLmin (and between SCRcalibrate and SCRmax \* SCRcalibrate / SCRmin, respectively) is divided to N sub-intervals for setting an ordinary scale. In this way, for N=3 (slow, moderate, and high arousal) reported tonic or phasic arousal will be high, if SCL or SCR feature varies between 67% and 100% of the difference (SCLmax \* SCLcalibrate / SCLmin - SCLmin) or (SCRmax \* SCRcalibrate / SCRmin - SCRmin).
2. At the end of the measurement, client program informs the asset for finalization of the measurement by calling the end of measurement method. This makes the client to update in its registry the Pmin\_mean and Pmax\_mean of each parameter, to register new absolute (for all the subjects) min and max values (if available from this measurement) and to increment the number of measured subjects N.

**Measurement requirements**

EDA sensors are attached to bottom of fingertips using Velcro straps wrap around fingers allowing continuous and relatively unobtrusive measuring of the signal. Practical hints:

1. Both EDA sensors should be placed to bottom of fingertips of the non-dominant hand for at least two minutes prior to the start of recording.
2. The experimental room must be quiet, with experimental temperature and relative humidity between 18–24 C and 30–6%, respectively.
3. Subject should not have performed any recent physical or mental exertion.
4. Subject needs to sit down comfortably, with arms resting on the armrest, and to remain as quiet as possible.
5. In order to avoid motion artefacts (e.g., due to movements performed with the other hand), a motion-restraining armrest could be used for the hand with attached sensors.

The measured raw signal is passed through a median filter, which filters noise without smoothing edges like filters using moving average. Next, the filtered signal is passed to a high-pass first order Butterworth filter with cut-off frequency of 0.5 Hz (Braithwaite et al., 2015) in order to separate phasic from the tonic component. The recorded signal is analysed using an automatic method for peak detection with a SCR threshold of 0.025 μS as far as preferred SCR thresholds are within the range 0.01µS - 0.03µS (Braithwaite, 2015). For example, (Boucsein, 2012) proposes a minimum amplitude threshold of 0.01 μS, while SCRs were identified as peaks in the signal with a minimum height of 0.05 μS (Chang et al., 2012). The high-pass filter removes the tonic component (the slow drift representing the SCL) of the raw skin conductance signal and passes only phasic changes more efficiently than using difference function (Naqvi & Bechara, 2006) or than computing a derivative of the raw EDA signal (Nagai et al., 2004). Sampling rate for EDA measurements is proposed to be no lower than 100-200 Hz (Figner & Murphy, 2010), thus, a rate of 256 Hz (with down sampling to 32 Hz) is supposed to be more than sufficient. Time window length could be arbitrary but too short interval bear the risk of strong influence of sudden fluctuations in measured signal value, while a rather long time window reduces the sensitivity of the adaptive loop. In affective games, time windows were found to differ from 0.025s to 180s (Bontchev, 2015). That´s why we propose to use time windows of 5-10 s.

The asset will receive a filtered raw signal from a simple, low cost biofeedback device allowing sampling rate from 8Hz up to 1kHz, using 8 times down sampling for averaging the signal. Measurements are carried out with two electrodes placed on two adjacent fingers. Recording, filtering and feature extraction might be executed on a computer (server) different than the game machine, in order to speed up all the required processing. The results will be communicated from the server-side to the client component in order to be used for game adaptation.

**Asset architecture and input/output**

Before starting with GSR measuring and arousal recognition, asset setup parameters should be initialised (by the client side). Such parameters include:

* required sample rate [Hz] – the frequency of measuring the GSR signal
* time window [s] – the length of time for calculating the features of the signal
* level of arousal [from 0 to N] – zero means no arousal at all and N means maximal level of arousal

The required sample rate [Hz] will be less than 1KHz. The calibration period [s], i.e. the time for baseline calibration, will be determined by experimental works and, next, set by the developer. Next, the client-side will expect receiving request for the indexed arousal level of the player and will reply to them in real time.

As well, he asset will be able to return values of several GSR features such as mean tonic activity level, phasic activity represented by mean and maximum amplitude of skin conductance response (all in micro-siemens), rate of phasic activity (response peaks/sec), SCR rise time, SCR 1/2 recovery time, and slope of tonic activity (in micro-siemens/sec).

Due to the intensive computing processing required for filtering and logging of the raw signal, as far as calculation of signal features, the asset is to be developed with a server and client side components communicating each other via sockets. Thus, the server component will be able to reside at a computer different than the one running the game.

**Asset API**

* **int SetSignalSamplerate(string speed)** – sets the frequency [in Hz] of measuring the GSR signal. Rate should be greater 1 and less than 100 and default sampling is 10Hz. It returns 0 in case of success. It returns 0 in case of success;
* **int GetSignalSampleRate()** - returns the current sample rate;
* **int SetTimeWindow(int time)** – the length of time [in seconds] for calculating the moving average, mean and standard deviation of the signal. The default time window is 10s. It returns 0 in case of success;
* **int SetMaxArousalLevel(int level)** – sets the max arousal level. Zero means no arousal at all and level means maximal level of arousal. The value of level should be greater than 0 and less than 10. The default value of the max arousal level is 7. It returns 0 in case of success.
* **double GetGSRFeature(string featureName)** – returns the value (as double number) of a specific GSR feature (featureName can be equal to "SCRArousalArea", "SCRAchievedArousalLevel", "SCLAchievedArousalLevel" and "MovingAverage)". It returns -1 if the device is not started (active);
* **void OpenPort()** - opens the device port;
* **void SelectCOMPort(string portName)** - choose port name of the GSR device. The default value is "COM3";
* **int StartSignalsRecord()** - starts the device. It returns -1 if the device is not started;
* **int StopSignalsRecord()** – stops the device. All the buffers are flushed. It returns -1 if the device is not stopped.

**Design and Implementation Tasks**

1. Asset architecture and API design
2. GSR Device design and development
3. GSR Device functionality tests
4. GSR signal read and visualization
5. GSR features and arousal metrics calculation
6. Asset testing (coverage/unit/integration/performance tests)
7. Asset documentation (API doc, deployment instruction, tutorial, demo documentation)
8. Asset demo
9. Asset bug fixing

**Examples of Use in Games**

Because of its simplicity and low cost techniques for measuring GSR (or EDA) continue to enjoy wide popularity - alone or combined with other techniques (Broek et al., 2009) to find correlations with the player experience and affective changes in player state. The most popular and simple stress detection algorithms based on EDA is proposed by Healey & Picard (1998), without requiring a signal baseline value recorded in advance when the player is in maximal relaxation. The GSR baseline varies greatly in different people (Schwartz, 1995), which makes direct comparisons of GSR levels across individuals not possible. Because of this reason, Bersak et al. (2001) used the general trend of the GSR signal over a selected time period for calibration of relaxation in their “Relax-to-Win” two players racing game. Depending on the sign of the signal slope calculated by means of a least squares approximation, object’s speed was increased or decreased until reaching defined threshold values. EDA was successfully used together with other physiological measurements within an affective adaptation of the Pong game for implementing performance-based DDA (Liu et al., 2009). EDA was used in (Chittaro & Sioni, 2014) for stress detection by identifying rising and declining intervals of the EDA signal sampled every 0.5s. Car steering, speed, and road visibility were dynamically adapted in a car racing game (Parnandi & Gutierrez-Osuna, 2014) by analysing phasic skin conductance within a time window of 30 seconds.

**Value**

GSR or EDA provides rather easy and cheap measuring. Besides that, GSR is less ambiguous than facial muscles’ activity and heart rate (Kivikangas et al., 2011). As a disadvantage of GSR (i.e., EDA), it should be mentioned that possible external factors may change the humidity of the skin, and thus its electrical conductivity, which can lead to inconsistent results. EDA is influenced both by the values of temperature and humidity of the environment and the intake of food and refreshing drinks (Sano, 2016). On the other hand, it must be taken into account that the reaction of EDA is not instantaneous and delays relative to the stimulus of 1 to 3 seconds.

Applying only EDA measurements for inferring emotional arousal and stress has a proven strong content validity as far as EDA is highly related to the arousal component of emotions (Fairclough, 2009). However, using EDA in isolation for recognition of any emotion leads to a weak content validity. Nevertheless, player’s arousal serves as an useful basis for game adaptation purposes. Studies represented in (Giakoumis et al., 2009) confirm both concentration and flow while playing video games increase EDA, which is an evidence for a combination of high arousal and pleasure.

**Dependencies**

There are no dependencies of this asset with the other assets. It can be used either in isolation or together the Real-time Emotion Detection Asset.

Naturally, asset use will be dependent on the GSR measuring device driver.

**Technical Details**

The asset will have only a client component. Its run-time requirements are as follows:

* Windows Vista or higher
* Microsoft .NET Framework

Source project requirements:

* Microsoft Visual Studio 2013 Professional to import the solution (project).
* Support for C#.

Technical details of the EDA measuring device:

* Processor: Atmel AVR
* Size: 90х50х15mm (as a match box)
* Weight: 60g
* Power supply and connection: USB
* Applied voltage: 0.5V
* Price: 150EUR for a single device
* Warranty: 2 years

**Licensing**

No specific licensing is required. However, the asset is dependent on usage of a custom EDA measuring device, although it could be redone for any other suitable EDA meter.

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1. In fact, log(SCR+1), in order to have determined value for SCR=0 [↑](#footnote-ref-2)
2. moving average of the GSR signal could be replaced by a median filtered GSR signal, in order not to lose min and maximum values of the signal. [↑](#footnote-ref-3)
3. The accuracy of the asset will be measured in a dedicated field trial with two phases: (1) calibration of GSR levels by measuring electro-dermal activity of volunteers, who are shown relaxing and next arousing videos and who are asked during or next to observation to self-report their felt arousal level, and next using machine learning methods; (2) calculation of arousal level by measuring GSR level of others volunteers using the same procedure in order to determine the accuracy of the arousal calculation. [↑](#footnote-ref-4)