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Individualized Stress Diagnosis Using Calibration and Case-Based Reasoning

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Abstract. Diagnosing stress is difficult even for experts due to large individual variations. Clinician's use today manual test procedures where they measure blood pressure, ECG, finger temperature and breathing speed during a number of exercises. An experienced clinician makes diagnosis on different readings shown in a computer screen. There are only very few experts who are able to diagnose and predict stress-related problems. In this paper we have proposed a combined approach based on a calibration phase and case-based reasoning to provide assistance in diagnosing stress, using data from the finger temperature sensor readings. The calibration phase helps to establish a number of individual parameters. The system uses a case-based reasoning approach and also feedback on how well the patient succeeded with the different test, used for giving similar cases reliability estimates.

1. Introduction

Stress is an increasing problem in our society. This Psychosocial and psycho-physiological stress can lead to different mental and physical problems that are often related to psychosomatic disorders, coronary heart disease etc. [15] Increased level of stress can cause permanent damages to the body. It is known that different treatments and exercises can reduce stress. For example the bio-feedback technique [14] can help the patient to train himself/herself in controlling stress. Since one of the effects of stress is that the awareness of the body decreases, it is easy to miss signals such as high tension in muscles, unnatural breathing, blood-sugar fluctuations and cardiovascular functionality. A system that notifies when stress levels are rising or too high is valuable in many situations, both in the clinical environment and in the other environments, e.g. the patients' home and work environment.

Although the stress-related symptoms are highly individual an experienced clinician learns with experience how to interpret the symptoms and diagnose a person's stress level. A computer-based system to diagnose stress and the risk of stress-related health problems would be valuable both for junior clinicians and as second opinion for experts. But it is difficult to build a computer-based system to diagnose stress due to these large individual variations and absence of general rules. A well known fact is that finger temperature has a correlation with stress for most of the persons, but individual fluctuations make it difficult to use it in automatic systems since there are no absolute values of temperature in relation to stress levels. The paper outlines a solution with case-based system incorporated with a calibration phase as illustrated in fig 1.

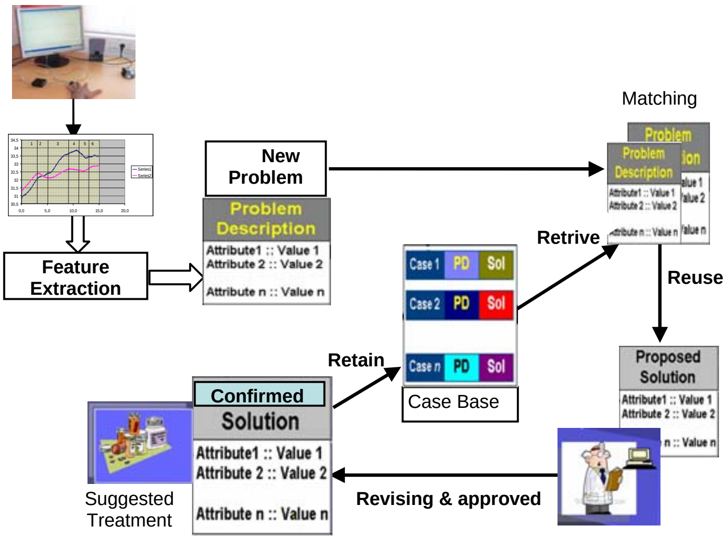

Fig. 1. Stress diagnosis system

The calibration phase helps to determine a number of parameters that are important inputs both for a clinician to make the final diagnosis and treatment plan. The case-based approach enables the system to identify similar patients and their treatment plans and success in treatment used by the clinician to make an as informed decision as possible.

2. Background and related work

The proposed approach is based on feature extraction from temperature signals and Case-based Reasoning (CBR) to detect appearance of stress. CBR [1, 7] is a method based on learning from similar cases founded on a cognitive model of human learning. CBR has shown to be successful in a number of different applications including medical applications. A CBR cycle with 4 steps as shown in fig 2: Retrieve, Reuse, Revise and Retain has been introduced by Aamodt and Plaza [1].

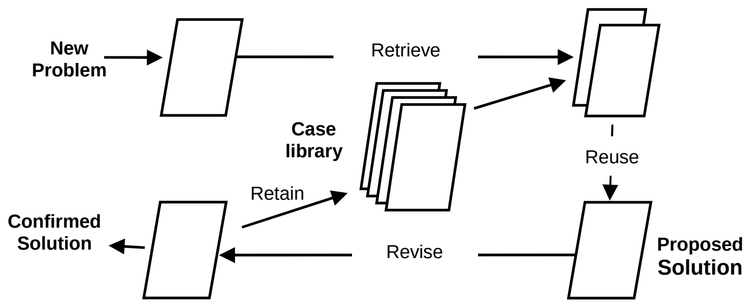

Fig. 2. CBR cycle. The figure is introduced by Aamodt and Plaza [1]

Most of the CBR systems follow this common cycle. In the retrieve step, for any new problem first a system tries to retrieve the most similar case(s) by matching previous cases from the case library. If it finds any suitable case that is closer to a current problem then the solution is reused (after some adaptation and revision if necessary).In the medical system there is not much adaptation, especially in a decision support system where the best cases are proposed to the clinician as suggestions of solutions. The clinician may revise the selected case and retain this new solution along with the new problem into the case library. CBR has been applied successfully when the domain theory is not clear enough or even incomplete. It is getting increasing attention from the medical domain since it is a reasoning process that also is medically accepted.

2.1 Related work

Some of the applications of CBR in the psycho-physiological domain are: A procedure using CBR for diagnosing stress related disorder by Nilsson et al. [9] where stress related disorders were diagnosed by classifying the heart rate patterns. A CBR system was outlined in [2] where the cases were fuzzified depends on finger temperature changes for diagnosing stress in the psycho-physiological domain, but it is not sufficient to depend on only the temperature changes to classify individual sensitivity to stress. Apart from the psycho-physiological domain, CBR techniques were applied in several other diagnosis/classification tasks in medical domain. Montani et al. [12] combined case-based reasoning, rule-based reasoning, and model-based reasoning to support therapy for diabetic patients. AUGUSTE [8] project was developed to diagnosis and treatment planning in Alzheimer’s disease. MNAOMIA [3] was developed for the domain of psychiatry. CARE-

PARTNER [4] was used in stem cell transplantation. All these projects and others [5, 11, and 10] show significant evidence of successfully applying CBR techniques in the medical domain.

3. Calibration phase

The procedure described below is used as a standard procedure in clinical work in patients with stress-related dysfunctions and an experienced clinician evaluates the measurements during the different test conditions to make an initial diagnosis.

We will give a brief description of the procedure without going into clinical details, and only give a general understanding of the test procedure. Measurement of the finger temperature is taken using a temperature sensor and the temperature evaluation is observed in 6 steps as summarized in table 1.

Table 1. Measurement procedure used to create an individual stress profile

Test step	Observation time	Con/Parameter	Finger temp
1.	3 min	Base Line	
2.	2 min	Deep Breath	
3.	2+2 min	Verbal Stress	
4.	2 min	Relax	
5.	2 min	Math stress	
6.	2 min	Relax	

Step1 may be seen as indicating the representative level for the individual when he/she is neither under strong stress nor in a relax state. Sometimes clinicians let the person read a neutral text during this step. A clinician not only identifies an individual’s basic finger temperature, but also notes fluctuations and other effects, e.g. disturbances in the environment or observations of person’s behaviors. Some changes in finger temperature might also be related to inactivation during sitting.

Step2 a person breaths deeply which under guidance normally causes a relax state. Also how quickly the changes occur during this step is relevant and recorded together with observed fluctuations.

Step 3 is initiated with letting a person tell about some stressful events she/he experienced in life. It is important for the clinician to make sure this really is a stressful event, since some persons instead select some more neutral event or tell about a challenge they were excited about to solve. During the second half of the step a person thinks about the negative stressful events in the life.

In *step 4* relaxation part, a person may be instructed to think of something positive, either a moment in life when he was very happy or a future event he looks forward to experiencing.

Step 5 is the math stress step; it tests the person's reaction to direct induced stress by the clinician where the person is requested to count backwards.

Finally, the relaxation *step 6* tests if and how quickly the person recovers from stress.

4. Classify person's sensitivity to stress

According to the clinical experts step 3 i.e. reactivity- which is defined as reactions during lab stress conditions and step 4 i.e. recovery – when persons are asked to try to relax after the stress condition is not just say recovery but coping with that recovery, are the most significant steps for the classifications. We find that different persons behave different in step 3 (talking about and thinking about a negative event) some have a very sharp drop in finger temperature, others a slow drop, a few have no drop in temperature (i.e. after lunch). Also some persons quickly recover in phase 4 (thinking positive event) others have slow increase in temperature, a few just continue dropping. According to the clinicians the later may be an indication of being more sensitive to stress, but in some case there are normal explanations for the cases (i.e. a person having an exam after the test or being very hungry) and they are probably not needing any treatment, but if this pattern is repeatedly consistent, then there may be a problem needing treatment. Also a stressed person may not reach a stable or relaxed state since the body is misadjusted. This can be caused by different illnesses or by long periods of increased stress. One indication of such an increased stress level may be that the difference between a stressed state (step 3) and a relaxed state (step 4) is small. Also the time it takes for a person to transfer from one state to an other state is relevant information for a clinician, e.g. a person that still has a finger temperature level that corresponds to stressed state after spending time on relaxation exercises may need a different treatment than a person quickly reaching a finger temperature corresponding to a relaxed state. This kind of reasoning is what clinicians often do, weighting different information. Therefore, the shape or 'behavior' in step 3 and 4 are significant to classify a person's sensitivity to stress.

We propose to introduce "degree of change" as a measurement for finger temperature change. A low value, e.g. zero or close to zero is no change in finger temperature. A high value indicating a steep slope upwards indicates a fast increase in finger temperature, while a negative angle, e.g. -20° indicates a steep decline. Together with clinicians we have agreed on a standardisation of the slope to make changes visible and patients and situations easier to compare. The proposal is that the X axis is minutes and the Y axis in degrees Celsius. Hence a change during 1 minute of 1 degree gives a “degree of change” of 45° see figure 3.

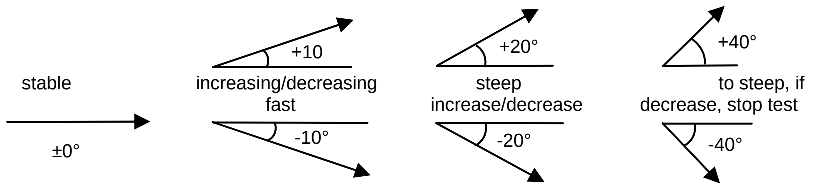

Fig. 3. Example of visualizations of temperature change, X axis minutes, Y axis 0.5 degree Celsius and clinicians response.

Decrease of temperature may be an indication of stress and how steep the change is also of importance for the clinicians. Using negative angles makes this more obvious and gives the clinician a terminology to reason about change. This is shown in figure 2 as text under the arrows.

If a clinician classifies temperature change we have to be aware that this also is context dependent, e.g. -17° decline may be classified “decreasing fast” for one patient and “steep decrease”. This is important e.g. when explaining a case to a clinician or explaining the differences and similarities between two cases.

In a test step both the average drop and the steepest drop during a time frame is relevant. The first step in the decision support system is to translate the curves into relevant sections of interest and calculate their angles as illustrated for step 3 in figure 4.

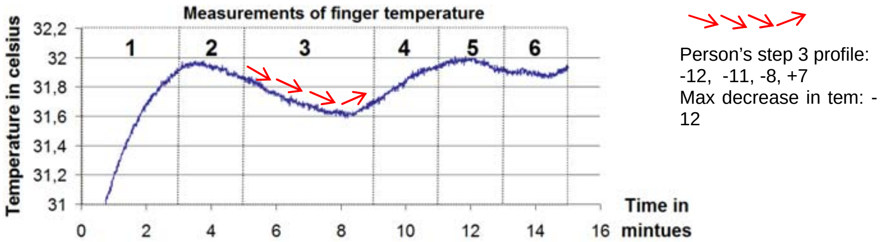

Fig. 4. The visualisations of temperature change and clinicians response

This notation makes it also easier to compare different person’s differences and similarities during the test cycle, despite that their finger temperature differs widely.

5. Case-based reasoning

Initial case library was build using some reference cases from the experts then the new cases are adapted and retained manually by the expert. The output from the calibration phase is used to create an individual case. This case will contain the derivative values of various important steps. We consider the temperature from step 3 to step 5 because these are the most significant steps to determine the sensitivity to stress according to the expert. Each step is divided in one minute time interval (4 minutes step 3 is divided into four time windows) and the derivative is calculated for each window. These values along with other attributes (gender, different between ceiling and floor temperature, etc) are stored into the case library with different weight values.

5.1 Similarity matching

The retrieval step is especially essential in medical applications since missed similar cases may lead to less informed decision. The reliability and accuracy of the diagnosis systems depend on the storage of cases/experiences and on the retrieval of all relevant cases and their ranking. Similarity measurement is taken to assess the degrees of matching and create the ranked list containing the most similar cases retrieved by equation 1

$$Similarity\ (C,S) = \sum_{f=1}^{n} w_f * sim(C_f, S_f) \qquad \textbf{(1)}$$

Where; C is the current case, *S* is a stored case in the case library, *w* is the normalized weight, *n* is the number of the attributes in each case, *f* is the index for an individual attribute and *sim* is the local similarity function for attribute *f* in case *C* and *S*.

For the numeric attribute values, the distances between two attributes values are calculated through the Euclidean distance shown in equation 2.

$$sim(C_f, S_f) = \left| C_f - S_f \right| \qquad \textbf{(2)}$$

After calculating the distance, this value is compared with the similarity values as depicted in table 2 where the similarity values for different matrices are defined by the expert.

Table 2. Different matrices for the similarity values

Similarity For step	
Distance	*sim*
0-2 degree	1
>2 and <4	0.8
>4 and <6	0.6
>6 and <8	0.4
>8 and <10	0.2
>10	0

Similarity for ceiling/floor	
	sim
>0,3	1
0,3 -0,5	0.8
0,5-0,7	0.4
<0,7	0

Hours since last meal					
T/S	0	1	2	3	>4
0	1	0.8	0.6	0.4	0
1	0.8	1	0.8	0.6	0.4
2	0.6	0.8	1	0.8	0.6
3	0.4	0.6	0.8	1	0.8
>4	0	0.4	0.6	0.8	1

Similarity for gender		
	m	f
m	1	0.5
f	0.5	1

So, finally the global similarity is calculated as a weighted sum of local similarities. An example is shown in table 3 where a current case is compared with two other stored cases (C_92 and C_115) in the case library.

Table 3. Similarity matching between cases

Attributes	**Local weight**	**Normalized weight**	**Current case**	**Stored case C_92**	**Similarity Function**	**Weighted similarity**	**Stored case C_115**	**Similarity function**	**Weighted similarity**
Gender	5	0.05	M	M	1.00	0.05	F	0.50	0.03
Hours since last meal	10	0.11	1	3	0.60	0.07	1	1.00	0.11
Room Temp	7	0.08	20	21	1.00	0.08	21.00	1.00	0.08
Step_3_part_1	7	0.08	-17.09	-1.39	0.00	0.00	-14.39	0.60	0.05
Step_3_part_2	7	0.08	-6.38	-10.91	0.60	0.05	-8.11	1.00	0.08
Step_3_part_3	7	0.08	-7.62	-7.55	1.00	0.08	-7.55	1.00	0.08
Step_3_part_4	7	0.08	1.52	3.15	1.00	0.08	3.15	1.00	0.08
Step_4_part_1	7	0.08	16.58	1.08	0.00	0.00	5.08	0.00	0.00
Step_4_part_2	7	0.08	8.34	6.34	1.00	0.08	7.13	1.00	0.08
Step_5_part_1	6	0.07	-8.66	-2.17	0.40	0.03	-6.17	0.40	0.03
Step_5_part_2	6	0.07	-9.44	-1.77	0.40	0.03	-1.77	0.80	0.05
Diff cealing /floor	9	0.10	0.75	0.59	1.00	0.10	0.59	1.00	0.10
					Global Similarity for C_92	**0.67**		**Global Similarity for C_115**	**0.80**

Here, the *Local weight (LW)* is defined by the experts, *Normalized weight (NW)* is calculated by the equation 3 where i=1 to n number of attributes, *Similarity function* calculates the similarity between attributes of the current case and the stored cases using the equation 2 and comparing the similarity values from the table 3, *Weighted similarity* for each attribute is defined by the normalized weight multiply the output of the similarity function, *Global similarity* between the cases are calculated as weighted sum of local similarities using the equation 1.

$$NW_i = \frac{LW_i}{\sum_{i=1}^{n} LW_i} \tag{3}$$

In table 3 the global similarity between the current case and case C_92 is 67% and current case and case C_115 is 80%.

The system returns a ranked list with the most similar cases. Cases are sorted according to the percentage where 100% means the perfect match and represented the solution with the classification shown in the previous section. From the table 3, case C_115 has higher rank than C_92 that is the current case is more similar to the case C_115. A threshold value can be defined and modified by the user to get a list of similar cases and this list of cases are treated as candidate cases. From these candidate cases a case can be proposed by the user as an acceptable case and that can be reused to solve the new problem. If necessary, the solution for this acceptable case is revised by the expert that is often important in the medical domain. Finally, the current problem with confirmed solution is retained as a new case and added to the case library. In terms of adaptation any changes can be done by the expert before adding it into the case library and this could be done manually.

5.2 Reliability of the test

Once the decision support system suggests a number of similar cases it is important for the clinician to know how reliable the similarity estimate is. One valuable indication of reliability in diagnosing stress is how well the person succeeded in doing the different test steps or how sure a clinician is on a given value or judgment. Such input will make the foundation for a confidence factor [5] for a case. A person can grade the severity of the stressful event (step 3) they were thinking on using a Visual Analogue Scale (-5 to +5) where +5 is very severe traumatic memory while 0 is not stressful and -5 is extremely positive. At the same time this input also need to be fuzzified due to many factors such as humans tend to give a precise answer without really having a basis for this “preciseness”.The value is fuzzified using two membership functions (*mf*s). The left linear mf (from -2 to +5) represents the fuzzy values for the negative range (rate of failure in test) and the right linear mf (from -5 to +2) represents the positive range (success in test) in the universe of discourse (-5 to +5) for the fuzzy variable scale. This will give a value for the success rate in some degree of mf instead of just a precise value and also reduced the number of rules to one.

For example in table 3, the current case (CC), C_92 and C_115 have the success rate for the test step 3,4, and 5 are CC(7,3,6), C_92(5,6,5) and C_115(8,4,3) respectively. On an average the differences in success rate between CC and C_92 is 2 and CC and C_115 is 1.6. Suppose the global similarity between CC and other two cases are same then according to their rate of success the case C_92 will get more preference. Besides the same global similarities, this rating helps the clinician able to take a closer look at the suggested cases when the global similarities among them are different.

6. Summary and conclusions

The decision support system based on CBR using a calibration procedure and a feedback process to estimate the reliability of the test bears similarities with how the clinicians work manually today. It allows us to utilize previous experience and at the same time diagnose the stress along with a stress sensitivity profile. This information enables the clinician to make a more informed decision of treatment plan for the patients. We also consider the judgment from the person who is doing the test to estimate the reliability of the individual test steps. This feedback is important for the clinician to make an overall decision. The concept and the functionality of the system are able to handle imprecise expert’s knowledge of the psycho-physiological domain. The evaluations based on 24 persons show promising results. The cases also enable following a patient’s treatment progress and compare it to other patients, and if differences, modification of treatment may be made. The approach also enables self treatment if the person has access to such a system together whit a previous clinical calibration. Once such a case library grows in size with cases it becomes a valuable clinical tool to discover causal relations that may be medically interesting and enable progress in diagnosis and treatment. The evaluation of the system during severe stress shows a clearly detectable stress reaction for most of the test persons. Only a few (8.5%) of them did not show any change in finger temperature during mild stress (some of these ranked there test success low). In our future work we will measure more patients and also identify alternative sensor placements.

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