

Tridimensional Fuzzy Pain Assessment

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Abstract—A tridimensional fuzzy pain assessment for representing professional, social, and sexual aspects concerned to the fifth vital sign of medical condition is proposed in this paper. According to the 3D fuzzy pain assessment herein, pain is not only caused by activity in nociceptive information in the brain. The proposed approach embodies such sensorial information simultaneously that contextualize it within cultural aspects that permeate the human life. This paper extends both previous unidimensional fuzzy pain intensity scale and the accepted professional-social-sexual pain assessment to fuzzy inference systems. The fuzzy professional-social-sexual pain assessment is able to represent the inherent physiological, psychological characteristics by taking into account the emotional, complex perceptual, subjective, and personal phenomenon involving all domains of an individual meanwhile can deal with cultural mechanisms within individual life experience. According to the proposed approach, not only fuzzy set theory but fuzzy systems can also direct and immediately improve medicine and healthcare in general, and pain assessment, in particular, in a subjective and multi-dimensional model.

Index Terms—Pain Assessment, Classification, Decision Support System, Fuzzy Logic, Artificial Intelligence, Computational Intelligence, Professional-Social-Sexual Disabilities

I. INTRODUCTION

Pain afflicts postoperative patients, patients with advanced cancer, residents in long-term care facilities, recipients of end-of-life care, for one side, and the elderly, the young, and minorities, on other side [1]. Further, there is no distinction between economical-social-sexual-racial characteristics; all individuals are subject to this vital signal in medicine and healthcare. Understood as the signal for diagnosing medical conditions related to the presence of disease or abnormality [2], [3], pain assessment is still a challenge for medical and healthcare professionals.

Many are the sources of difficulties for medical and healthcare professionals. The foremost challenge is, mostly, concerned to the patient's self-report intensity during physical examinations; the preferable indicator of pain. Pain is, primary, determined by sensorial information. Stimulus in free endings of thin myelinated and nonmyelinated fibers sends nociceptive information to pain receptors (Nociceptors) in the brain that

detect noxious agents [4]. Related to genetic composition, there is a huge variability in the pain perception and pain expression for the same painful stimuli [5].

Intensity is, however, not the only aspect employed to define pain. Due to its nature, it is not only physiological but psychological, as well. Being a perception, pain is considered an emotional, complex perceptual, subjective, and personal phenomenon involving all domains of individual life experiences [5]. The challenge in pain assessment for representing basic bodily functions and health quality of life also encompass pain-related disability, pain duration, pain affect etc. [6]. Cultural mechanisms and derived social aspects such as individual life experience, learned behavior, daily life activities, only to mention few, affect patient's pain perception [7], [8]. Pain is, thus, understood as a multi-faceted subjective response related to a biopsychosocial experience.

All these characteristics encompass a variety of clinical scenarios and make pain assessment and management a complex task for therapeutic decisions. To improve pain assessment and management, fuzzy set theory is employed in [5] to address the subjectivity of the pain intensity reported by patients. The most common, international standards (systematic mechanisms) related to unidimensional intensity rating assessment are modified by using fuzzy set theory yielding fuzzy visual analog scale (FVAS), fuzzy numerical rating scale (FNRS), fuzzy qualitative pain scale (FQPS), and fuzzy face pain scale (FFPS). Therein, possibility distribution functions are used to best represent the inherent imprecision, uncertainty and vagueness related to the fifth vital sign of medical condition, present in the pain report and assessment. Such an approach is used as an alternative to build up a fuzzy pain assessment system [9].

Unidimensional fuzzy pain intensity scale was first chosen due to its immediate and general applications, for one side, and the reinforcement of the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) for using easier tools as the key element for successful pain assessment and treatment [10], on the other side. Nevertheless, unidimensional pain measurements fail in capturing other elements and aspects that

can influence the perception of the patients.

Pain can be assessed by employing unidimensional or multidimensional mechanisms according to the objective and interests to be achieved during diagnosis. This paper addresses the use of fuzzy set theory and fuzzy logic to represent multi-faceted, tridimensional pain assessment encompassing pain-related disability, i.e., pain-related interference with activities. Along with this real-world, ordinary life activities are professional, social, and sexual (PSS) features as examples of cultural mechanisms that compose such a behavior pain assessment. This paper extends both previous unidimensional fuzzy pain intensity scale and the international professional–social–sexual pain assessment to synthesis a fuzzy inference system able to gather the inherent physiological, psychological, and cultural mechanisms within individual life experiences.

II. TRIDIMENSIONAL FUZZY PAIN ASSESSMENT

For each of the different aspects concerning pain, different assessment instruments should exist. Measurement of pain intensity does not capture sensory, affective, behavioral, social, and attitudinal factors. Along with pain intensity, pain-related interference with activities is seen as a major indicator for the severity of a pain condition [6], [11].

A. 3-D Professional–Social–Sexual Pain Assessment

Behavioral and social limitations are important elements for pain measurement. For instance, dressing, walking, family life, sexual relationship, professional performance etc. are examples from simple to complex activities affected by pain. Unfortunately, this list extends so far.

Several pain assessment approaches have been developed to assess the pain-related disability. These approaches assess the limitations in different activities of daily living. A list of multi-faceted, multi-items, multidimensional pain measures is detailed in [11].

The literature points out professional, social, and sexual limitations as three great groups for classifying pain-related disabilities. Tridimensional Fuzzy Professional–Social–Sexual (FPSS) Pain Assessment is, thus, proposed in this paper.

B. 3-D Fuzzy Professional–Social–Sexual Pain Assessment

Taking into account the inherent imperfection (uncertainty, imprecision, vagueness) present in this natural phenomenon, fuzzy set theory is a primary approach for representing pain [5]. While a unidimensional fuzzy set, M_i , can immediately be employed to represent unidimensional pain intensity, n -dimensional fuzzy sets:

$$M_{(1,\dots,i,\dots,n)} = M_1 \cap \dots \cap M_i \cap \dots \cap M_n \quad (1)$$

can be an alternative for describing multidimensional pain conditions. N -dimensional fuzzy sets advantage of gathering distinct characteristics associated to an object under analysis, each one represented, respectively, by distinct universes of discourse, X_i . The fuzzy sets can be represented by simple fuzzy propositions, $P_i = \langle x_i \text{ is } M_i \rangle$, in a natural or synthetic

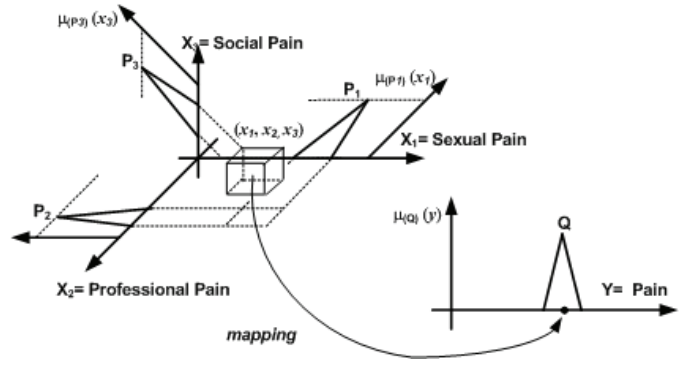


Fig. 1. Tridimensional Fuzzy Pain Measurement

language. In general, simple fuzzy propositions when put together allow building compound fuzzy propositions:

$$P_1 \text{ AND } \dots \text{ AND } P_i \text{ AND } \dots \text{ AND } P_n \quad (2)$$

such that, the intersection set operation, $\cap$, in (1) corresponds to the linguistic expression, AND in (2). Further, the resulting value can yet be related to fuzzy classes by employing a fuzzy inference mechanism also denominated *fuzzy conditional proposition* as given as:

$$\text{IF } P_1 \text{ AND } \dots \text{ AND } P_i \text{ AND } \dots \text{ AND } P_n \text{ THEN } P_{n+1}, \quad (3)$$

Due to its equivalence to linguistic expressions in the form of arguments to represent rules of inference it is associated to human approximate reasoning.

In this paper, professional–social–sexual pain-related disabilities are simultaneously represented in a tridimensional premise space, as depicted in Fig. 1, and mapped into an output associated to pain assessment, in the general form:

$$\begin{aligned} R_i : \text{IF } \langle \text{professional pain is } M_{ij}^{\text{professional}} \rangle \text{ AND } \dots \\ \langle \text{social pain is } M_{ij}^{\text{social}} \rangle \text{ AND } \dots \\ \langle \text{sexual pain is } M_{ij}^{\text{sexual}} \rangle \\ \text{THEN } \langle \text{disability pain is } N_{ij}^{\text{disability-pain}} \rangle, \quad (4) \end{aligned}$$

where the elements $M_{ij}^{(\cdot)}$ and $N_{ij}^{(\cdot)}$ are fuzzy sets (also named *linguistic terms*) partitioning the respective universes of discourse, X_k and Y . The amount of partitions is given by $j(\cdot) = 1, \dots, m_{(\cdot)}$ such that $M_{j(\cdot)}^{(\cdot)}(x_k) \subset X_k \forall k = 1, \dots, n$ and $N^{\text{disability-pain}} \subset Y$. The number of rules is given by $i = 1, \dots, N_r$. The input vector of the premise is given by $x = [x_1, x_2, x_3]^T$, while the output is associated to y . The input variables are *professional pain* $\in X_1$, *social pain* $\in X_2$, *sexual pain* $\in X_3$ while the output variable is *disability pain* $\in Y$. As proposed, $n = 3$ in this paper determines the number of input universes of discourse and represents the tridimensionality of the premises.

The universes of discourse of the proposed 3-D fuzzy pain measurement is equivalent in structure to Fuzzy Qualitative Pain Scale (Fig. 1). The FQPS consists of a verbal rating

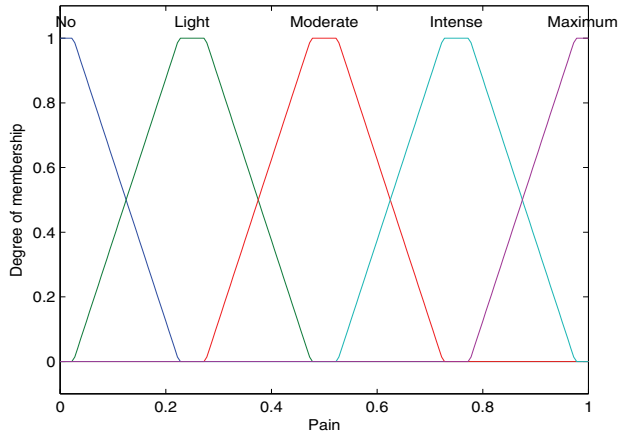


Fig. 2. Equivalent structure of Unidimensional Fuzzy Quality Pain Scale (FQPS) to input and output universes of discourse for Fuzzy Professional–Social–Sexual (FPSS) pain assessment

scale in which categories are labeled with words. Each of the input and output universes of discourse can, thus, adopt the same linguistic terms and number of partitions. In the FQPS, the patient is asked to classify the pain intensity according to linguistic expressions (adjectives) from a list of (1) *no pain*, (2) *light pain*, (3) *moderate pain*, (4) *intense pain*, (5) *maximum pain*. The linguistic expressions for representing pain may be directly represented by fuzzy sets as depicted in Fig. 2 [5]. In so doing, the linguistic terms $M_{j_{\text{professional}}^{\text{professional}}}$, $M_{j_{\text{social}}^{\text{social}}}$, and $M_{j_{\text{sexual}}^{\text{sexual}}}$, respectively, with $j_{\text{professional}} = j_{\text{social}} = j_{\text{sexual}} = 1, \dots, 5$, yield a set of 125 fuzzy regions in the tridimensional input space, as illustrated in Fig. 1.

The 3D Fuzzy PSS pain assessment is, thus, represented as

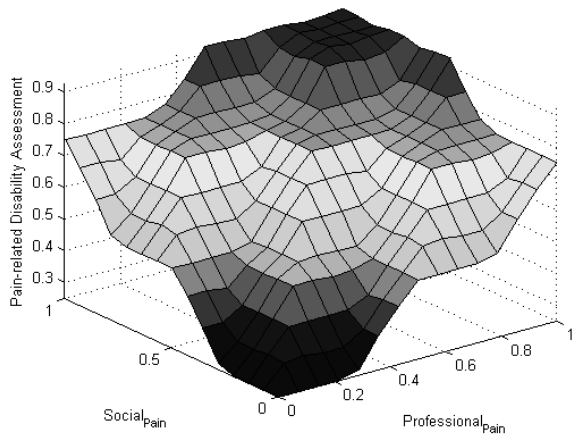


Fig. 3. Social and professional input relationship to pain-related disability degree of severity.

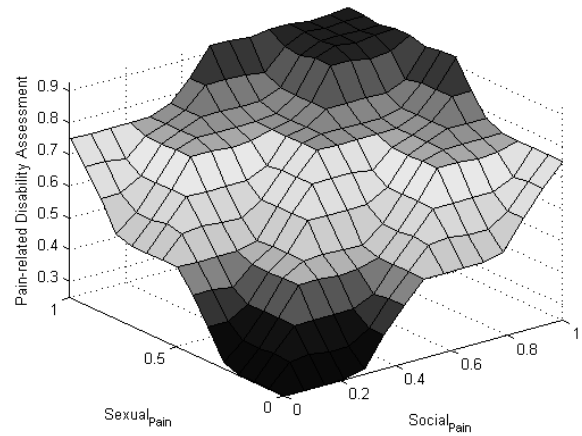


Fig. 4. Sexual and Social input relationship to pain-related disability degree of severity.

IF-THEN *fuzzy rules* in the form:

$$\begin{aligned} R_1 : & \text{IF } \langle \text{professional}_{\text{pain}} \text{ is No}_{\text{professional}} \rangle \text{ AND } \dots \\ & \quad \langle \text{social}_{\text{pain}} \text{ is No}_{\text{social}} \rangle \text{ AND } \dots \\ & \quad \langle \text{sexual}_{\text{pain}} \text{ is No}_{\text{sexual}} \rangle \\ & \text{THEN } \langle \text{disability pain is No}_{\text{disability}} \rangle , \\ R_2 : & \text{IF } \langle \text{professional}_{\text{pain}} \text{ is No}_{\text{professional}} \rangle \text{ AND } \dots \\ & \quad \langle \text{social}_{\text{pain}} \text{ is No}_{\text{social}} \rangle \text{ AND } \dots \\ & \quad \langle \text{sexual}_{\text{pain}} \text{ is Light}_{\text{sexual}} \rangle \\ & \text{THEN } \langle \text{disability pain is Light}_{\text{disability}} \rangle , \\ & \dots \end{aligned}$$

$$\begin{aligned} R_{124} : & \text{IF } \langle \text{professional}_{\text{pain}} \text{ is Maximum}_{\text{professional}} \rangle \text{ AND } \dots \\ & \quad \langle \text{social}_{\text{pain}} \text{ is Maximum}_{\text{social}} \rangle \text{ AND } \dots \\ & \quad \langle \text{sexual}_{\text{pain}} \text{ is Intense}_{\text{sexual}} \rangle \\ & \text{THEN } \langle \text{disability pain is Maximum}_{\text{disability}} \rangle , \\ R_{125} : & \text{IF } \langle \text{professional}_{\text{pain}} \text{ is Maximum}_{\text{professional}} \rangle \text{ AND } \dots \\ & \quad \langle \text{social}_{\text{pain}} \text{ is Maximum}_{\text{social}} \rangle \text{ AND } \dots \\ & \quad \langle \text{sexual}_{\text{pain}} \text{ is Maximum}_{\text{sexual}} \rangle \\ & \text{THEN } \langle \text{disability pain is Maximum}_{\text{disability}} \rangle . \end{aligned} \quad (5)$$

The fuzzy IF-THEN rules in (5) are denominated *fuzzy model*, as well. In this way, the proposed 3D Fuzzy PSS pain assessment is, actually, a fuzzy model for pain assessment when behavior and disability aspects are taken into account.

The proposed fuzzy professional–social–sexual pain assessment may be employed with any shape of fuzzy sets available in literature. Here, trapezoidal membership functions are utilized to illustrate the proposed approach. The resulting fuzzy pain-related disability assessment when concerning social–professional input variables, sexual–social input variables, and

professional–sexual input variables are, respectively, depicted in Fig. 3, Fig. 4, and 5.

C. Singleton Pain and Fuzzy Pain Measurements in Fuzzy PSS Pain Assessment

The fuzzy model for PSS pain assessment works as an alternative when interested in reporting behavior and disability aspects. The fuzzy professional–social–sexual pain assessment advantages in being able to deal with both singleton and fuzzy pain measurement for any of the input dimension (Fig. 6).

Singleton pain measurement can be obtained by employing, for instance, but not limited to, visual analog scale, numeric rating scale, verbal rating scale, change in back pain intensity, increased pain during or after exercise, low back pain rating scale, pain frequency, pressure pain threshold, 5-point categorical, 6-point categorical, 11-point intensity. They can immediately be used to supply singleton inputs for the fuzzy PSS assessment system, as depicted in Fig. 6(a).

Nevertheless, emotional states and in doubt individuals when reporting their pain perception are related to the absence of crisp boundaries and singleton values. An international standard proposed for pain assessment based on fuzzy sets and fuzzy numbers for representing inaccuracy, flexibility, doubt, and emotionality in pain intensity measurement is described in [5]. Likewise occurs with singleton pain measurement scales, fuzzy visual analog scale (FVAS) and fuzzy numerical rating scale (FNRS) are alternatives for supplying fuzzy inputs for the fuzzy PSS assessment system, as depicted in Fig. 6(b).

Visual comparative analysis among classic Visual Analog Scale (VAS) and Numerical Rating Scale (NRS) and FVAS, FNRS are, respectively, depicted in Figs. 7 and 8. When using the fuzzy visual analog scale, the value of pain intensity is obtained by the distance from the beginning of a 10 cm single line assigned in one border labeled *no pain* and in the other extremity *maximum pain* to the patient's marks. This distance is directly measured in centimeters by employing a ruler or by using a computational system [9]. While the classic visual

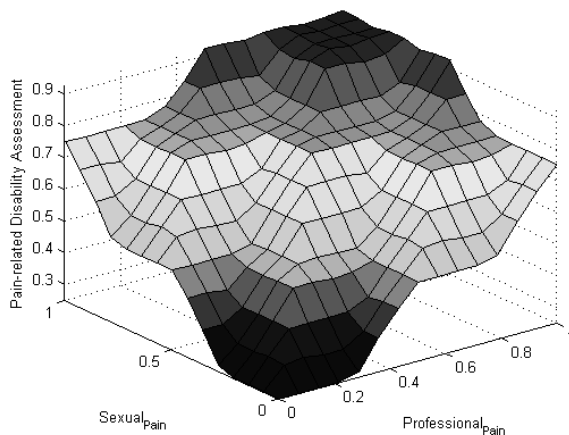
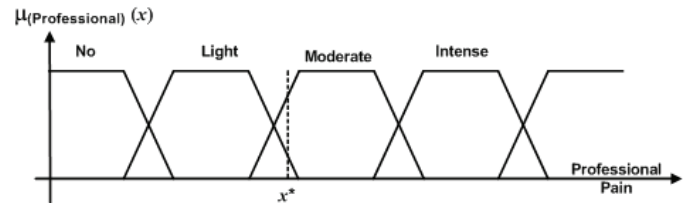
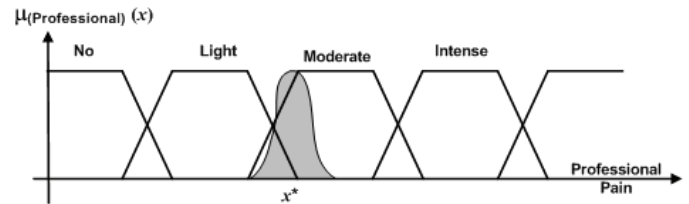


Fig. 5. Professional and sexual input relationship to pain–related disability degree of severity.



(a) Singleton Pain Measurement into FPSS.



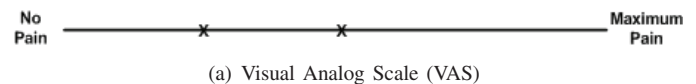
(b) Fuzzy Pain Measurement into FPSS.

Fig. 6. Both types of singleton and fuzzy pain measurement supplied to FPSS pain assessment, for instance, into professional pain dimension.

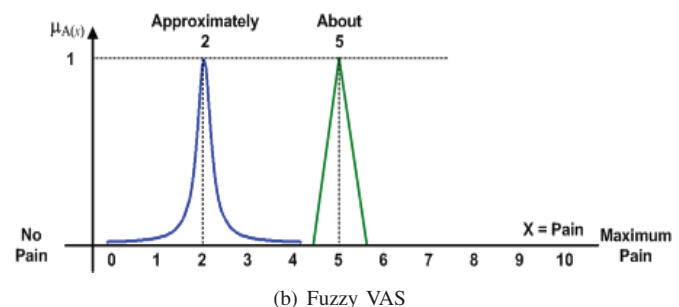
analog scale is represented as a singleton value, the fuzzy visual analog scale is able to represent the inaccuracy in the pain indication (Fig. 7(b)) by using fuzzy sets [5].

Similarly, fuzzy numerical rating scale consists of a graded line scale identified by eleven numbers from 0 to 10 (Fig. 8(a)). The patient marks this scale with the pain intensity that better represents the assumed physical discomfort. The value of pain intensity is obtained by the distance from the beginning of the graded line to the patient's marks. This distance is directly measured in centimeters by employing a ruler or by using a computational system [9]. While the classic numerical rating scale is represented as a singleton value, the fuzzy numerical rating scale uses a fuzzy set to represent the subjectivity, vagueness in indication of the pain (Fig. 8(b)) [5].

It is worth mentioning that nothing prevents the use of mixed singleton and fuzzy pain measurements for representing behavior and disability pain condition.



(a) Visual Analog Scale (VAS)



(b) Fuzzy VAS

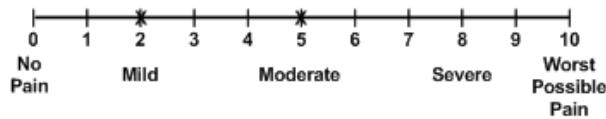
Fig. 7. Unidimensional Fuzzy Visual Analog Scale (FVAS).

D. Exemplifying Patient's Self-Report Fuzzy Behavioral and Disability Pain Modeling

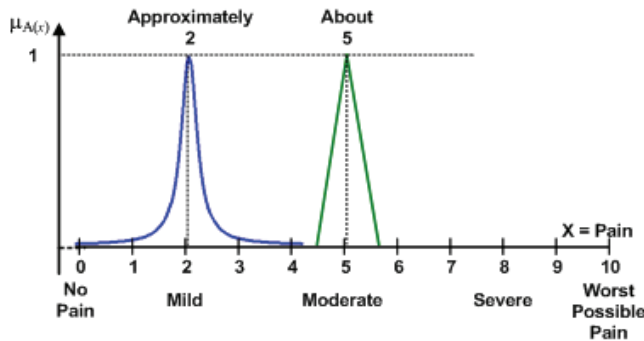
Consider a patient who reports social and professional difficulties due to the presence of a back pain during medical diagnosis. The patient declares the interest in not getting out due to the pain. Working in security, the back pain assumes a more important role because the patient carries a revolver. Further, the afflicted pain does not limit the sexual experience but a patient's self-report pain measurement indicates a small discomfort.

Simple, unidimensional pain scales can, at first, be used to identify the pain intensity, be it a singleton or fuzzy measure. Nevertheless, being able to capture presence and intensity, they do not determine the real significance of the pain. The preferable indicator of pain must capture the importance of not being able to adequately handle a revolver. The intensity pain scale does not measure the impact and social frustration upon patient's family due to the limitation imposed by the patient's pain. Neither, the sexual discomfort is taken into account.

The tridimensional pain-related disability model presented in (4) is a feasible alternative for comprehensively representing the inherent complexity, subjectivity comprising this sort of pain. In this illustrative example, it is considered the simplest condition. A singleton pain scale is furnished to the patient who, in turn, marks three distinct amplitudes for professional, social, and sexual pain according to the well established NRS. It was required first to the patient to mark the intensity of pain, i.e., marking a unidimensional pain scale. Second, it is asked to the patient to include not only intensity of pain but limitations and other aspects concerning each one of the input premises for completely describing the suffering. These marks are presented in Fig. 9. Distinct values among the four pain measurements based on real-world data (patients)



(a) Numerical Rating Scale (NRS)



(b) Fuzzy NRS (FNRS)

Fig. 8. Unidimensional Fuzzy Numerical Rating Scale (FNRS)

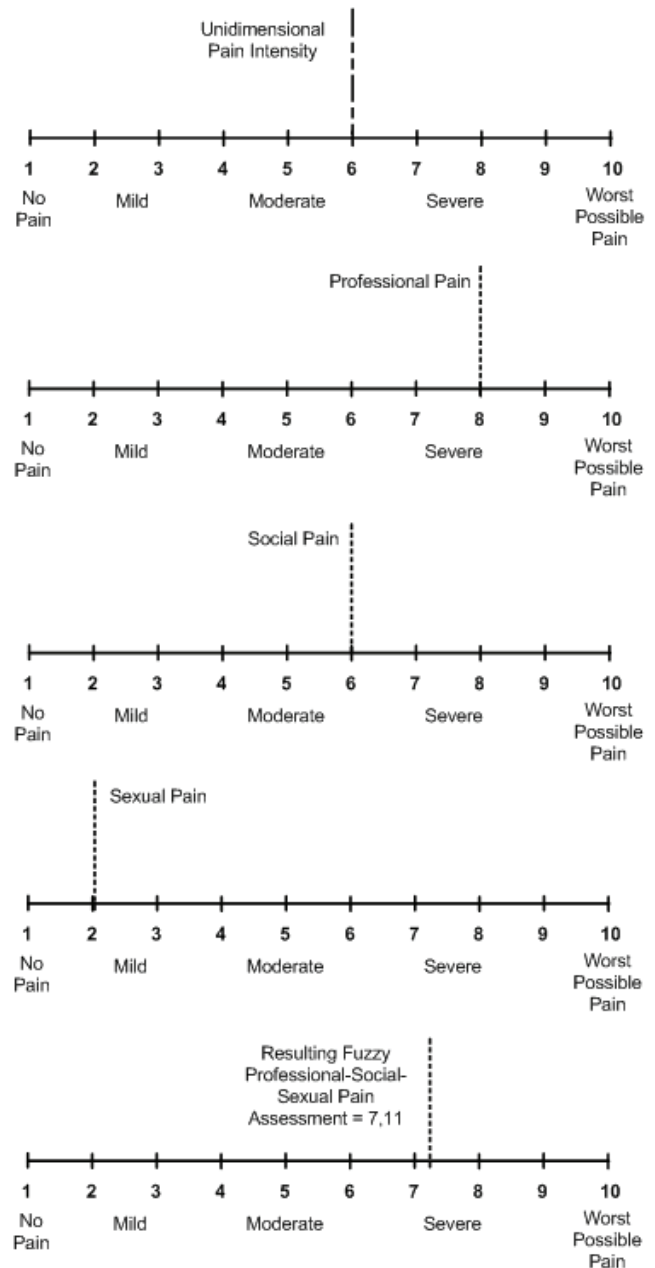


Fig. 9. Trade-off between Fuzzy Professional-Social-Sexual Pain Assessment and Classic Unidimensional Pain Intensity Measurement.

are: (a) simple intensity of pain, (b) professional pain, (c) social pain, and (d) sexual pain. Notice yet the (e) resulting fuzzy professional-social-sexual pain value computed by a 3D Fuzzy PSS pain assessment system.

III. CONCLUSION

In this paper a novel, feasible approach for modeling pain-related behavioral and disability assessment based on fuzzy set theory and fuzzy logic is presented. Professional pain, social pain, and sexual pain are three great groups for classifying pain-related disabilities used for generating a tridimensional fuzzy pain modeling. The proposed approach advantages of

being able to deal with both with singleton and fuzzy pain input measurements. Each input dimension can assume singleton pain values, or fuzzy pain values, or yet a mixed singleton and fuzzy pain values. The proposed fuzzy professional–social–sexual pain assessment is able not only of capturing sensory, affective, behavioral, social, and attitudinal factors concerning presence and intensity of afflicted pain but determine the real significance of the pain according to the inherent complexity, subjectivity comprising behavioral and disability aspects. The 3–D FPSS is a comprehensively manner to describe the physiological, psychological, and cultural present in mankind pain condition.

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