称号及び氏名	博士(応用生命科学)　Mirwan Ushada
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論　文　名	Bird Swarm Algorithm in Kansei Engineering to derive Consumer Satisfaction （鳥群飛アルゴリズムによる消費者の満足感を誘導する感性工学手法）
論文審査委員	主査　村瀬　治比古 副査　藤浦　建史 副査　北村　進一 副査　小山　修平

論文要旨

Kansei engineering was founded by Mitsuo Nagamachi (1995) as a method to extract Kansei value into design attributes. Kansei value is a Japanese value which means the consumer's psychological feeling and image regarding a new product design. A design attribute is a convertible product parameter which states a consumer satisfaction. In Japan, the Ministry of Economy, Trade and Industry (METI) has designated the three years from Fiscal Year 2008 to 2010 as the 'Kansei Value Creation Year'. Therefore, METI is intensively implementing research to create Kansei value and communicate it to people both in Japan and abroad.

Kansei satisfaction is defined as satisfaction of a consumer segment which is stimulated by Kansei value. It can be categorized as a complex problem because: (1) As a social group, consumer satisfaction is influenced by their mentality constraints during early stages of design; (2) It is a multimodal computational problem. This problem is confirmed by Japanese Ministry of Agriculture, Forestry, and Fisheries (MAFF). MAFF (2006) suggested that agricultural industry should maximize satisfaction by minimizing discrepancy between Kansei value and design attribute.

This dissertation utilizes Kansei engineering to formulate problem of Kansei satisfaction. The inputs represent Kansei values which are initial attributes importance and consumer mentality constraints. The attributes included those that consumers say are not important to them, or that consumers do not mention, but that if met, strongly affect satisfaction. The output is a set of satisfied design attributes. Kansei fitness function is proposed to model satisfaction by extracting multimodal probability of attributes importance. The objective is to maximize satisfaction. The function can be categorized as an optimization problem and highly multimodal computational problem. In this respect, a number of problem solutions for consumer satisfaction have been reviewed and none of them were related to Kansei value. Bio-computing approach is required to solve Kansei satisfaction problem due to the limitations of the exact methods. This approach studies how biological-inspired algorithm can help out with computational problems.

In order to model consumer segment as a social group, a bio-computing theory of social simulation of organized flight in bird can be used. Craig W. Reynolds (1987) developed a social simulation of organized animal motion such as bird flocks. The basic simulation consists of three simple steering behaviors which describe how an individual virtual bird maneuvers based on the positions and velocities its nearby social group. This simulation was confirmed in the latest theory of organized flight in natural birds by Iztoc L. Bajec and Frank H. Heppner (2009).

In order to solve multimodal computational problem, a bio-computing theory of Particle Swarm Optimization (PSO) can be used. James Kennedy and Russel C. Eberhart (1995) proposed PSO which is inspired from swarming strategy of animals to optimize the specific objectives.

This dissertation proposed a modified theory of bird swarm optimization from social simulation of bird and PSO strategy. The aim of this dissertation is to propose a problem solution for Kansei satisfaction by using Kansei engineering and a modified bio-computing of bird swarm optimization. Kansei Engineering-inspired Bird Swarm Algorithm (KEBISA) was developed based on the analogy between Kansei engineering and bird swarm optimization.

In bird swarm optimization, the existence of predator constraints limited the movement of swarm. The birds behave as a swarm and make various movements to find food in safe sources against various predators according to theory of Selous (1931). Individual members determined their velocities by two factors, their own best previous experience and the best experience of all other members. They change this information with their neighbor in the form of global best position. This global best will guide their motion to the optimal source which is safe from constraints.

In Kansei engineering, the existence of mentality constraints limited Kansei satisfaction. Therefore KEBISA simulated a consumer segment to behave as a bird swarm in determining whether a design attribute is satisfied or not against their mentality constraints. Consumers consider their own best past experience and the best experience of other people around them. The same satisfaction that guided them can be simulated as if they exchange information. In Kansei fitness function, the probability of attribute importance is used to represent the visibility of birds in line formation. The formation is typical of large birds such as waterfowl, where birds fly arranged in single lines and joined together.

The inputs of KEBISA are initial attributes importance and mentality constraints. In this respect, we offer some initial attributes to two different consumer segment using 5-point Likert response questionnaires. These attributes could be Kansei values which were generated from preliminary observation. Attributes are extracted by predicting its importance in Kansei fitness function. The function is optimized based on mentality constraints. Subsequently, each predicted and measured attribute importance was quantified into Weighted Average Importance Index (WAII) and Consistency Index (CI) to determine whether an attribute is satisfied or not.

The objectives of this dissertation were: (1) To develop KEBISA based on the analogy between Kansei engineering and bird swarm optimization; (2) To demonstrate the applicability of KEBISA for Kansei satisfaction; (3) To extract Kansei value into a set of satisfied design attributes. The expected advantage is to support decision in various designs for Kansei value-added product.

The dissertation is organized as follows:

In Chapter 1, the introduction of the dissertation is described. Sunagoke greening product (*Rhacomitrium japonicum*) is used as a case study to demonstrate the applicability of KEBISA. Kansei value of Sunagoke can be identified based on its water content. Questionnaires result by Ushada and Murase (2009) have summarized that 82.3% of Japanese consumers are satisfied with wet Sunagoke and 66.7% of Indonesian are satisfied with semi-dry Sunagoke.

In Chapter 2, three basic theories are described to be applied in the remaining chapters. The first theory is artificial life. It became a new research branch of applied life science from the later 1980's. It is being developed by applied life scientist, computer scientists, biologist, social psychologist, mathematicians, and evolutionary theorists. Artificial life includes two research topics: (1) Computational techniques for biological system; (2) Bio-computing. Bio-computing includes social simulation of bird and PSO. The second theory is Kansei engineering procedure to formulate problem of Kansei satisfaction. It consists of reference samples, design attributes, attribute importance and mentality constraint. The third theory is related to algorithm. A modified theory of bird swarm optimization was described in detail and how it was modified from social simulation of bird and PSO theories.

In Chapter 3, KEBISA is proposed based on the modified theory in Chapter 2. KEBISA is initialized with a swarm of random candidate solutions. A virtual bird is defined as a candidate solution for probability of an attribute importance. Probability of attribute importance is formulated as randomly generated within a pre-specified upper and lower boundary of mentality constraint. Boundary of mentality constraint limited movement of a virtual bird in searching space to maximize satisfaction in Kansei fitness function. This boundary is adapted from theory of predator which influences the organized flight in birds (Selous, 1931). It compares its current objective function with the best that it has ever attained so far. The best position associated with the best objective function is called the individual best. The global best is referred to as the best position among all the individual best positions achieved so far. After obtaining velocity updating formula, each virtual bird moves its corresponding position. Each predicted and measured attribute importance was quantified using WAII and CI. WAII is an abstractive parameter of consumer on how maximum the offered product is meeting their satisfaction. CI is a parameter of accuracy indicated the consistency between a consumer segment's measured satisfaction in questionnaire and their maximum WAII performance predicted from KEBISA. A design attribute is satisfied if the CI value equal or more than 1. Subsequently, KEBISA is verified with some numerical functions. Numerical verification indicated that KEBISA is ready as a solution for optimization problem.

In Chapter 4, the proposed algorithm in Chapter 3 was demonstrated using questionnaires data of Sunagoke. A total of 130 new consumer candidates were selected as respondents. These respondents were clustered into two segments based on different limited mentality constraints. Each importance of 24 initial attributes was predicted based on 15 mentality constraints. Thirty virtual birds and 1000 iterations were used by sensitivity analysis. Three satisfied design attributes were extracted for wet and semi-dry Sunagoke as ‘Easy Maintenance’, ‘Waterproofing’, and ‘Comfortable’. Validation concluded that these attributes were applicable for different segment with minimum error. In addition, benchmarking results concluded that KEBISA performs better than Bayesian belief network for predicted WAII.

In Chapter 5, Kansei satisfaction was analyzed using abstractive parameter of design attributes in Chapter 4 and verified. The analysis indicated consistency patterns for maximum WAII and CI values of each attribute in different initial virtual bird population and consumer segments. It can be concluded that WAII is possible as an abstractive parameter of a design attribute for maximizing satisfaction while CI for minimizing discrepancy. Finally, these attributes were successfully verified using noisy and clustered data. These attributes confirmed obvious patterns that Japanese are satisfied with wet Sunagoke and Indonesians with semi-dry Sunagoke.

In Chapter 6, the results in this dissertation are generally discussed and concluded. Some perspectives for future works are given. KEBISA is applicable as a problem solution for Kansei satisfaction. A consumer segment can be simulated as a bird swarm to maximize Kansei satisfaction against their mentality constraints

審査結果の要旨

「消費者の満足感」に関する問題は次に示す 2 つの特質から解析困難な問題に位置づけられる．(1)消費者の満足感は新製品開発などものづくりの初期段階からその心的制約条件(知識，馴染み，興味，好み，その他)に影響されること．(2)消費者の満足感を最適化する問題であること．本論文においては「消費者の満足感」に関する問題に対して感性工学手法を駆使しすることで解決に導く．

消費者の満足感を扱う問題では解析的方法よりもバイオコンピューティングのような適応的方法が有効と考えられる．バイオコンピューティングのような適応的方法論の応用は，生物システム由来のアルゴリズムなどが生物系の最適化問題の解決処方としてその有用性が示されている．本論文で用いる生物システム由来アルゴリズムは鳥群飛の挙動を活用したアルゴリズムで，社会性の強い消費者グループなどのモデル化に活用可能である．鳥群飛のシミュレーションモデルは，近辺を飛ぶ仲間の位置と速度を個々の鳥が感知して群れ全体が整然と飛び続けるために必要な 3 つの簡単な規範から構成されている．

ここで開発したアルゴリズム(BISAKE)においては，消費者が認識すべきデザイン属性が彼らの心的制約条件下で評価される過程があたかも天敵の存在という制約条件下で鳥の群れが餌を探し当てるようなアルゴリズムになっている．消費者は自身の経験と近隣の人々の経験を考慮する．彼らは情報を共有することでいずれも同じように満足感を得ることができる．一般の感性適合関数においては，デザイン属性の重要度は確率で示されるが，鳥群飛アルゴリズムでは，群飛過程における視野内の仲間の数で表す．BISAKE の入力データは初期デザイン属性の重要度および心的制約条件である．感性適合関数を用いて重要度を計算し，その要件を抽出する．感性適合関数は心的制約条件の下で最適化される．続いて，おのおのの推定あるいは観測したデザイン属性の重要度は荷重平均指標および整合度で表し，要件が満たされているかについて判断する．

本論文の目的は:

1. 鳥群飛アルゴリズムの開発すること，
2. 鳥群飛アルゴリズムを用いて消費者満足感の解析法を確立すること，
3. 感性価値を一組のデザイン要件として表現する手法を確立すること．

これらの目的が達成されると感性価値を付加価値とする製品作りに有用な手法が確立する．

第 1 章においては，本研究の位置づけ(問題提起と解決方法)，目的(新規アルゴリズムの開発,その応用)，および期待される有用性，理論検証のための実験方法として緑化用スナゴケ資材生産における鳥群飛アルゴリズムの適用法など研究全体の構成について述べた．

第 2 章においては，鳥群飛アルゴリズム開発の基盤となる，人工生命，生物システム由来アルゴリズム，鳥社会システム，小動物郡最適化法，感性工学において適用されるデザイン属性や制約条件の概念などを紹介し，鳥群飛アルゴリズム開発へのアプローチを示した．

第 3 章では鳥群飛アルゴリズムを示し，仮想鳥群をコンピュータ上に用意し，開発アルゴリズムの性能評価を行った．予め定めた解候補を仮想鳥群に置き換えて，感性価値空間に心的制約条件で境界を設け，仮想鳥群を活動させて感性適合関数を用いて満足感の最大値を与える仮想鳥群のパターンを同定した．

第 4 章では，実際に緑化用スナゴケを生産物(商品)として用い，特定の商品についての感性価値の発掘とそれに伴う消費者に満足感を与える商品の具備すべき要件から満足感を最大にする全プロセスを実際のアンケート調査結果と開発した鳥群飛アルゴリズムを用いた実証結果を検証して開発アルゴリズムの有効性を確認した．130 人の被験者に対して 24 初期属性と 15 メンタル制約条件を与えて，アンケートを実施した．また，シミュレーションでは，30 羽の仮想鳥群で 1000 回の繰り返し計算を行った．検証結果は良好で，3 種のデザイン要件が抽出された．

第 5 章は感性満足感について解析を行った．前章で用いた要件の中で抽象的なデザイン要件について荷重平均重要度指数と適合度を計算したところ鳥群の初期サイズおよび被験者グループの差異に影響されないことが明らかとなった．したがって，荷重平均重要度指数と適合度を指標としそれぞれ最大化および最小化することで感性満足感を最大化できることが確認できた．

以上，本研究は鳥群飛アルゴリズムを開発することにより消費者満足感の解析を可能とし，感性価値を一組のデザイン要件として表現する手法を示した．これにより感性価値を付加価値とする製品作りに有用な手法を確立した

本研究の成果は，応用生命科学の発展，とりわけ生物情報科学の新たな展開に貢献するものであり本論文の審査ならびに最終試験の結果と併せて，申請者に対し，博士(応用生命科学)の学位を授与することを適当と認める．