MULTI-PERSPECTIVES EVALUATION AND BENCHMARKING OF REAL-TIME SIGN LANGUAGE RECOGNITION SYSTEMS BASED ON FUZZY MULTI-ATTRIBUTE DECISION ANALYSIS

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UNIVERSITI PENDIDIKAN SULTAN IDRIS

2022

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THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

FACULTY OF ART, COMPUTING & CREATIVE INDUSTRY
SULTAN IDRIS EDUCATION UNIVERSITY

2022

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ACKNOWLEDGMENT

"In the name of Allah, the Most Gracious and the Most Merciful"

Alhamdulillah, first and foremost, praise be Allah, the Cherisher and Sustainer of the World and to the Prophet Muhammad (Peace and Blessings of Allah Be upon Him) who was sent by Allah to be a great teacher to the mankind.

Special thanks to my supervisor, Dr. Abdullah Al-Amoodi, my co-supervisor A.P. Dr. Mashitoh Hashim, as well as my previous supervisors Dr. Osamah Albahrey and A.P. Dr. Aos Alaa Zaidan for their guidance and advice throughout the research, their patience, kindness, interjecting a healthy dose of common sense when needed.

My heart overflows with gratitude and warmest appreciation to my beloved family, starting with my parents Mr. Sabah Al-Samarraay and Ms. Suad Al-Tekreeti who provided me with their love and support for both moral and financial throughout the journey of my study. Also, I don't forget my lovely son Zayn Al-Rayyan for his presence in my life. My special thanks go to my sisters Noor and Mina and their families for always being there in supporting me. My gratitude and appreciation for my best friend Dr. Jameel R. Al-Obaidi, Mr. Raheem A. Hasan and all my relatives and friends for being very much supportive and understanding. I would like to extend my appreciation to all those who involved and give a helpful hand in ensuring the success of this research.

This research would not have come to fruition without all your help and supports.
Thank you. Allah blesses you.

ABSTRACT

The real-time Sign Language Recognition Systems (SLRSs) have been developed recently to assist the deaf and dumb community in translating hand gestures to their spoken language equivalents. However, the multidimensional evaluation and benchmarking of these systems considered a Multi-attribute Decision-Making (MADM) problem due to the presence of several issues, including multiple evaluation criteria, multi ortance, and criteria confliction. In this study, a new extension of the Fuzzy Decision by Opinion Score Method (FDOSM) for evaluating and benchmarking SLRSs is developed under a Pythagorean Fuzzy Set (PFS). Fundamentally, the methodology divided into 4 phases. The first phase is the preliminary study, while the construction of the decision matrix is the second phase, then the third phase is the formulation of the proposed methods, and the fourth phase is the results evaluation. Results indicate the following: (1) individual benchmarking results of real-time SLRS showed high variation based on the preference of each Decision Maker (DM). (2) The group benchmarking results for Pythagorean Fuzzy Decision by Opinion Score Method - Interactive Hybrid Arithmetic Mean *PFDOSM-IHAM* indicate that the *29th* real-time SLRS was the best, whereas the worst real-time SLRS was attributed to SLRS (*6th*). While the results of group benchmarking for Interval-Valued Pythagorean Fuzzy Decision by Opinion Score *Method IVP-FDOSM* reveal that the 10th real-time SLRS was the optimal one and the 6th was the worst. In addition, the rates of ranking match between the group benchmarking and each DM captured and discussed from analytical perspective. (3) for the results evaluation, two MADM assessments, namely, systematic ranking and comparative analysis are used to validate the robustness of the proposed MADM methods. The research contributed to the deaf – mute community by providing the suitable SLRS selection bases on their life needs, benefiting the SLRS industrial field, and the special education centers.

PENILAIAN PELBAGAI PERSPEKTIF DAN PENANDAARASAN SISTEM PENGECAMAN BAHASA ISYARAT MASA NYATA BERDASARKAN ANALISIS KEPUTUSAN PELBAGAI KRITERIA FUZZY

ABSTRAK

Bagi membantu komuniti Orang Kurang Upaya Pekak dan Bisu dalam mengalihbahasakan bahasa isyarat tangan kepada bahasa pertuturan harian, teknologi masa nyata Rangkaian Sistem Pengendalian Bahasa Isyarat (SLRSs) telah dibangunkan. Walaubagaimanapun, penilaian dan penanda aras pelbagai dimensi sistem ini telah dikenalpasti sebagai masalah dalam kepelbagaian dalam pembuatan keputusan "*Multicriteria Decision Making*" *(MCDM),* disebabkan oleh beberapa komponen penting seperti kriteria penilaian, kepentingan kriteria dan konflik kriteria yang perlu dititikberatkan. Dalam kajian ini, satu perkembangan Penilaian kabur atau *Fuzzy Decision oleh Opinion Score Method (FDOSM)* bagi penilaian dan penanda aras SLRSs dibangunkan di bawah *Pythagorean Fuzzy set (PFS)* dan juga *IVPFS* dinamakan sebagai *PFDOSM-IHAM* dan *IVP-FDOSM*. Secara asasnya, kaedah ini dibahagikan kepada empat fasa. Fasa pertama adalah kajian awal. Manakala fasa kedua adalah pembangunan matriks keputusan. Fasa ketiga pula melibatkan formulasi cadangan kaedah dan fasa keempat melibatkan penilaian keputusan. Hasil dapatan kajian menunjukkan (1) Keputusan penanda aras individu berdasarkan realiti-masa *SLRS* menunjukkan kepelbagaian variasi berdasarkan kecenderungan setiap DM. (2) Keputusan penanda aras berkumpulan bagi *PFDOSM-IHAM* menunjukkan realiti-masa *SLRS* ke-29 adalah yang terbaik, manakala realiti masa *SLRS* yang ke-6 adalah yang terburuk. Sementara itu, keputusan bagi penanda aras berkumpulan bagi *IVP-FDOSM* mendedahkan bahawa realiti masa SLRS yang ke-10 adalah yang paling optimal dan yang ke-6 adalah yang terburuk. Selain itu, kedudukan sepadan di antara kumpulan penanda aras dan setiap DM telah dikenalpasti dan dibincangkan melalui analisis perspektif. (3) Bagi penilaian keputusan, statistik menunjukkan bahawa sistem pendanda aras daripada *PFDOSM-IHAM* dan IVP-FDOSM mengambilkira kedudukan sistematik. Selain dari itu, perbezaan analisis menunjukkan bahawa *PFDOSM-IHAM* dan *IVP-FDSOM* adalah lebih baik dari segi kedudukan dan keberkesanannya berbanding kaedah *MCDM* yang menggunakan *Pythagorean* angka kabur. Kajian ini memberi sumbangan kepada komuniti pekak dan bisu dengan memberikan pemilihan SLRS yang sesuai dengan keperluan hidup mereka dan seterusnya menyumbang kepada bidang industri SLRS, iaitu kejuruteraan dan penubuhan perkilangan. Kajian ini juga mempertingkatkan keupayaan pusat pendidikan khas dan organisasi saintifik.

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LIST OF ABBREVIATIONS

ACC	Accelerometers
ADC	Analog-to-Digital Converter
AHP	Analytic Hierarchy Process
AM	Arithmetic Mean
ANN	Artificial Neural Networks
ASL	American Sign Language
BWM	Best–Worst Method
COPRAS	Complex Proportional Assessment of Alternatives
CRF	Conditional Random Field
CSL	Chinese Sign Language
DM	Decision Maker
DoF	Degrees of Freedom
EMG	Electromyography
FDOSM	Fuzzy Decision by Opinion Score Method
FLD	Fisher’s Linear Discriminant
GDM	Group Decision Makers
GLCD	Graphical Liquid Crystal Display
GLV	CyberGlove
GM	Geometric Mean
GMCDM	Group Multi Criteria Decision Making
HM	Harmonic Mean
IFS	Intuitionistic Fuzzy Set

IHAM	Interactive Hybrid Arithmetic Mean
IMEn	Intrinsic-Mode Entropy
IMU	Inertial Measurement Unit
IPFWA	Interval-Valued Pythagorean Fuzzy Weighted Averaging
IPFWG	Interval-Valued Pythagorean Fuzzy Weighted Geometric
IVP-FDOSM	Interval-Valued Pythagorean - Fuzzy Decision by Opinion Score Method
IVPFS	Interval-Valued Pythagorean Fuzzy Set
LDA	Linear Discriminant Analysis
LED	Light-Emitting Diode
MADM	Multi Attribute Decision Making
MCDM	Multi Criteria Decision Making
MCGDM	Multicriteria Group Decision-Making
MKNN	Modified k-Nearest Neighbor
MULTIMOORA	Multi-Objective Optimisation on the basis of Ratio Analysis Plus Full Multiplicative Form
PaHMM	Parallel Hidden Markov Models
PCA	Principal Component Analysis
PFDOSM-	Pythagorean Fuzzy Decision by Opinion Score Method -
IHAM	Interactive Hybrid Arithmetic Mean
PFS	Pythagorean Fuzzy Set
PFULV	Pythagorean Fuzzy Uncertain Linguistic Variable
PIC	Programmable Intelligent Computer
PSL	Pakistan Sign Language
RMS	Root Mean Square

SD	Secure Digital
SEE	Signing Exact English
SL	Sign Language
SLRS	Sign Language Recognition System
SVM	Support Vector Machine
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
VIKOR	VlseKriterijumskaOptimizacija I KompromisnoResenje
VQPCA	Vector Quantization Principal Component Analysis
WFD	World Federation of the Deaf
WHO	World Health Organization
ZSG	Zero-Sum Game

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the research topic, the statement of the problem, and research objectives. This chapter also presents the scope of this research where the experimental and technical scopes are explained. A brief background of the research components is presented in Section 1.2. The statement of the problem, on which the direction of the research is based, is identified, and introduced in Section 1.3. This is followed by the objectives of the research, which are described in Section 1.4 followed by the research questions listed in Section 1.5. Moreover, the scope of the study is discussed in Section 1.6. the significant of the study is presented in Section 1.7. The main structure of the research is briefly outlined in Section 1.8. Finally, a summary of the chapter is presented in Section 1.9.

1.2 Research Background

According to the statistics of the World Federation of the Deaf (WFD) and the World Health Organization (WHO), approximately 70 million people in the world are deaf-mute. Over 5% of world's population with a total of 432 million people are deaf who mostly have profound hearing loss, which implies very little or no hearing, and 34 million of these individuals are children. Deaf and dumb people use their hands instead of their voices to communicate with others due to their loss of speaking/hearing ability (Young, Oram, & Napier, 2019). Most of the speech- and hearing-impaired people cannot read or write in regular languages, hence the hand is an essential element of the deaf–dumb language vocabulary named Sign Language (Kaur and Kumar (2016).

Sign Language (SL) is a visual–spatial language based on positional and visual components, such as the shape of fingers and hands, the location and orientation of the hands, arm, body movements and facial expressions (V. Sharma, Kumar, Masaguppi, Suma, & Ambika, 2013).

Thus, SL is a native language used by the deaf and mute to communicate with others and it relies primarily on gestures rather than voice to convey meaning. Therefore, the mentioned SL components are used together to convey the meaning of an idea. The phonological structure of SL generally has five elements (Figure 1.1). Each gesture in SL is a combination of five building blocks. These five blocks represent the valuable elements of SL and can be exploited by automated intelligent systems for SL recognition (SLR) (Ramli, 2012).

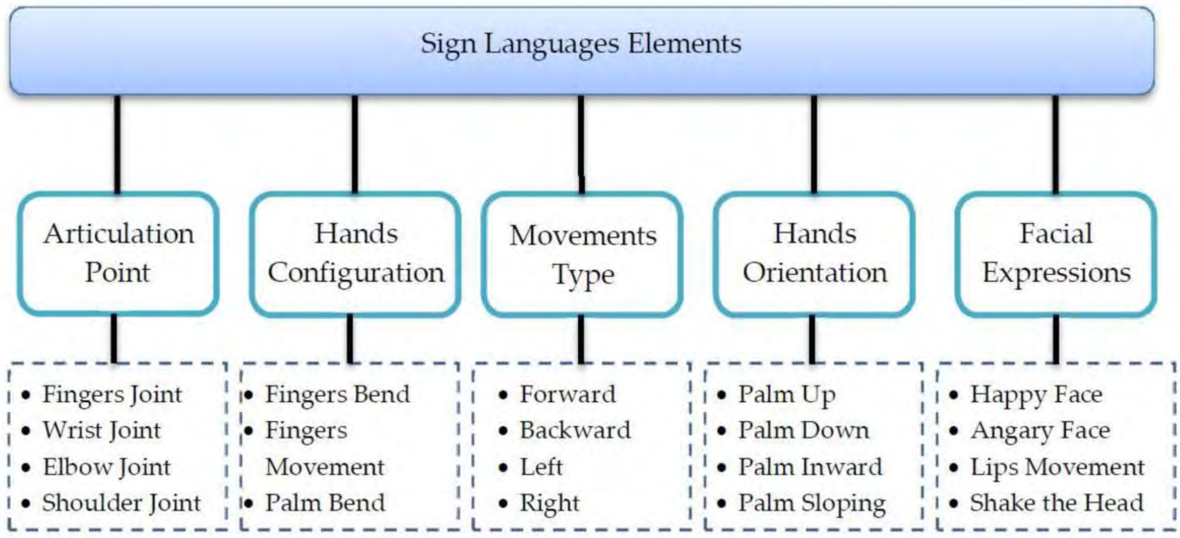

Figure 1.1. The Essential Elements Related to Sign Language Gesture Formation. (M. A. Ahmed, Zaidan, Zaidan, Salih, & Lakulu, 2018)

Only a few people practice sign language (SL) due to two reasons: the inherent complexity of sign language due to a lot of hand movements, a limited vocabulary and learning difficulties, and the lack of motivation to learn such a language.

The aforementioned reasons cause human suffering for deaf people by imposing on them the reality of living in isolation due to communication barrier with ordinary people. This communication barrier adversely affects the lives and social relationships of deaf people (Bhatnagar, Magon, Srivastava, & Thakur, 2015). Thus, a translator, which is necessary for communication with the deaf, must be supplied to translate sign language signs into a spoken language and vice versa (McKee, Moran, & Zazove, 2020). However, having an interpreter at all times is an unrealistic solution. Therefore, an automatic sign language translation system based on gesture recognition is required to allow dumb people to communicate with able individuals (M. A. Ahmed et al., 2018).

Therefore, the SLRSs have gained considerable attention, and this can be seen in the amount of research and studies for various cases and languages people to minimize the human suffering by living in isolation for the deaf people due to communication barrier with ordinary people (Oudah, Al-Naji, & Chahl, 2020). However, the proper evaluation of the SLRSs and obtain the best SLRS among many other SLRSs based on the SLRS criteria perspectives (which is called benchmarking) is a challenging task and persisted as a research gap.

1.3 Problem Statements

There is an increasing of works related to sign language with various cases and languages, including Arabic Sign Language (N. B. Ibrahim, Selim, & Zayed, 2018), Chinese Sign Language (Gao, Fang, Zhao, & Chen, 2004), Thai Sign Language (Pariwat & Seresangtakul, 2021), Bangle Sign Language (Basnin, Nahar, & Hossain, 2021), English Sign Language (Wadhawan & Kumar, 2020), American Sign Language (ASL) (Kadam, Ganu, Bhosekar, & Joshi, 2012) and many others (Sriram & Nithiyanandham, 2013) (Tateno, Liu, & Ou, 2020).

However, with all the available recognition systems and their remarkable availability, a standardised and unified system with all perfect desirable features is essential and yet to be presented. Furthermore, various systems will show considerable differences considering their respected aspects. Nevertheless, the studies focused on evaluation criteria for the multidimensional nature of real-time sensor based SLRS from different perspectives (M. Ahmed et al., 2021). These criteria are classified and grouped, namely, hand gesture recognition and sensor glove system. The hand gesture recognition group includes six main criteria, which are (1) dataset (Aly & Aly, 2020), (2) gesture type, (Jaiswal & Gupta, 2021) (3) sign type (Jaiswal & Gupta, 2021), (4) misclassification error (Bui & Nguyen, 2007) (Abualola, Al Ghothani, Eddin, Almoosa, & Poon, 2016), (5) recognition system (Sekar, Rajashekar, Srinivasan, Suresh, & Vijayaraghavan, 2016) and (6) communication. Meanwhile, the sensor glove system group includes five main criteria, which are (1) system cost (Sekar et al., 2016), (2) data channels (Adnan et al., 2012), (3) number of hands (Borghetti, Sardini, & Serpelloni, 2013), (4) finger movements (Borghetti et al., 2013) and (5) hand movements. In addition, some of these criteria may have sub-criteria. For instance, the dataset includes the following sub-criteria: (i) number (Rosero-Montalvo et al., 2018), (ii) alphabet (Abualola et al., 2016), (iii) word/phrases (Jadhav & Joshi, 2016), (iv) gesture number (Arif, Rizvi, Jawaid, Waleed, & Shakeel, 2016) (v) participants (Borghetti et al., 2013), (vi) repetition (Jaiswal & Gupta, 2021) and (vii) size (Aly & Aly, 2020).

Thus, a perfect fit amongst all the works presented for SLR based on the sensory approach is almost impossible. Hence, a comparison between the SLRSs based on a certain perspective (i.e., measure of difference) is unfair due to these differences. Therefore, effectively comparing the performance of recognition systems has become challenging to their users considering the determination of the most suitable application or the most advanced recognition system. This phenomenon is a difficult process but can be addressed with the evaluation of these recognition systems towards understanding the most suitable method.

Simultaneously, evaluating such recognition systems is difficult not only because of these recognition systems but also the evaluation challenges, which might play a role in the evaluation process. Several evaluation issues, which include (i) multiple criteria, (ii) criterion importance and (iii) conflict criterion (M. Ahmed et al., 2021), must be tackled in the evaluation and benchmarking of recognition systems for sign language to bridge the identified research gap. These issues are faced with several criteria for the evaluation process.

Therefore, the evaluation process in the SLRS falls under a complex multi-attribute decision analysis problem. This problem motivates researchers to develop a multi-attribute decision making (MADM) solution, which includes all performance aspects of the evaluation of SLRSs. Such a solution can be used to determine the best recognition systems for sign language.

On other hand, to select most suitable and powerful MADM method, (Salih, Zaidan, & Zaidan, 2020) presented the latest MADM method called fuzzy decision by opinion score method (FDOSM), which considered the concept of an ideal solution, reduced the number of comparisons, defined fair and implicit understandable comparisons, prevented inconsistency, reduced vagueness and yielded a minimum number of mathematical operations.

The first version of the FDOSM focused exclusively on the arithmetic mean (AM) operator in the direct aggregation MADM approach whilst neglecting the other operators. Simultaneously, FDOSM neglected the application of the distance measurement and the compromise rank MADM approaches, which is a serious issue that may lead to different ranking results. Consequently, the FDOSM was extended to consider the other direct aggregation operators, which include geometric mean (GM), harmonic mean (HM) and root mean square (RMS), and distance measurement and compromise rank were applied to identify the best alternative to be used with FDOSM (O. S. Albahri et al., 2021). However, the FDOSM and its extension rely on triangularly fuzzy sets. However, TFN has limitations in handling vagueness and uncertainty (J.-j. Peng, Wang, Wang, Yang, & Chen, 2015). MADM techniques contain preferences and subjective judgements of DMs, including quantitative and/or qualitative criteria ratings. These issues can be imprecise, indefinite and uncertain, thereby complicating the decision-making process when applied to real-world problems (Borghetti et al., 2013).

Thus, to obtain a standardised and unified system with all perfect desirable features, FDOSM must be modified and extended into another fuzzy type to overcome the uncertainty issues and capture additional helpful information under imprecise and uncertain conditions and effectively evaluate and benchmark SLRS.

1.4 Research Objective

The objectives of this research are listed as follows:

1- To analyze the academic literature of the evaluation of the sign language recognition systems and identify the challenges and research gap.

2- To propose a decision matrix for the evaluation of the sign language recognition systems.

3- To benchmark the proposed decision matrix based on a new formulation of

Pythagorean Fuzzy Decision by Opinion Score Method

4- To evaluate the proposed method based on systematic ranking and comparative analysis assessment.

1.5 Research Questions

The questions of this research are listed as follows:

1. What are the available evaluation approaches and their related challenges of sign language recognition systems?
2. How to create an evaluation decision matrix for the sign language recognition systems?
3. How to formulate a new MADM method?
4. Why the evaluation process for the proposed SLRS benchmarking method is important?

1.6 Research Scope

This research is a cross-domain involving engineering and expert system algorithms. The research was designed to solve the problem of SLRSs evaluation and benchmarking. Different research methods are involved in the study. The case study in which American Sign Language (ASL) used in the research.

The outcomes of the research indicate the research type. The main output expected from this study is an evaluation and benchmarking methodology performed via several steps that improve the process of SLRSs selection.

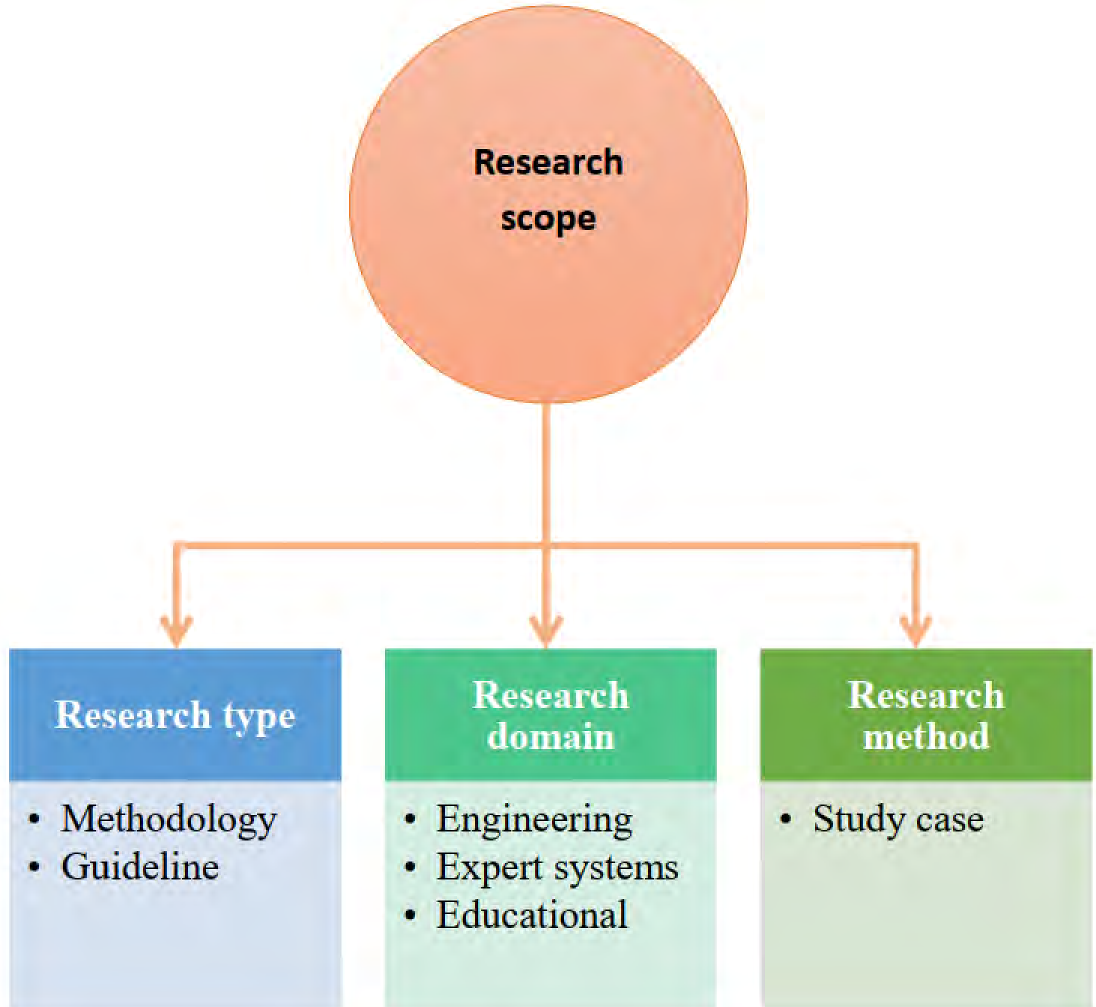

Figure 1.2. General Scheme and Scope of the Study.

Furthermore, the proposed MADM method will be integrated to improve the performance of the SLRSs from the perspective of development. The proposed method will be evaluated statistically; moreover, various scenarios and checklist benchmarking will be presented to evaluate the proposed evaluation and benchmarking methodology. The general scheme for our research and the view that represents the research method, research type, and research domain are presented in Figure 1.2.

1.7 Research Significant

The field of SLRSs has gained considerable attention because it offers obvious benefits. In this section, the benefits and significance of this research presented, which are organized into three categories according to related benefits. The corresponding significant are presented for further discussion as below:

1.7.1 Benefits to People with Deaf – Mute Disability

By looking at the statistics of World Health Organization (WHO) on the increasing number of the people with deaf and mute disability, hence the benefit to allow the deaf and mute people to compare and select the right SLRSs accurately to what suit their daily life needs. As a result, this work will contribute to minimize the human suffering for deaf and mute people. Therefore, one of the main objectives of this study is to provide a proper method for the selection to the SLRSs based on the evaluation and benchmarking which is contributing towards improving the deaf and mute people's reality of living in isolation due to communication barrier with ordinary people.

1.7.2 Benefits to Engineering and Manufacturing Establishments

The evaluation and benchmarking of SLRSs is useful for the engineers and the developers who are involve in developing the SLRS hardware and software component as it will provide for them a huge assist to decide which criteria needs to focus on or enhance during the development of the SLRS when it comes to devices' design, components, software, features', etc. which can be determined based on the evaluation and benchmarking results.

1.7.3 Benefits to Special Education Centres and Scientific Organizations

The evaluation and benchmarking of SLRs can be used to solve the discussed selection problem for SLRSs, hence this will help to provide a guideline for the evaluation and benchmarking the SLRSs application which can be used by the educational organizations for deaf and mute students by selecting the most suitable SLRS for case-to-case basis depending on the deaf-mute disability level, mode of education, subjects, language and other needed factors for the evaluation and benchmarking.

1.8 Operational Definitions

In this section, numerous terminologies mentioned in this research were defined as shown in the below Table 1.1.

Table 1.1

Operational Definitions.

Number	Terminology	Definition
1	Deaf-mute	is a term which was used historically to identify a person who was either deaf and used sign language or both deaf and could not speak.
2	Sign Language	is a visual–spatial language based on positional and visual components, such as the shape of fingers and hands, the location and orientation of the hands, arm, body movements and facial expressions
3	Sign Language Recognition	is a computational task that involves recognizing actions from sign languages.
4	Vision based Sign Language Recognition	is an approach that widely adopted in sign language recognition which utilizes an RGB camera and depth sensor and applies computer vision algorithms to analyze the hand gestures and body and facial expressions from images to recognize sign language
5	Sensor based Sign Language Recognition	is an approach that widely adopted in sign language recognition which utilizes sensors to analyze the hand gestures and body and facial expressions from hand movement to recognize sign language
6	Hybrid System for Sign Language Recognition	is an approach that combines vision- and sensor-based approaches for acquiring sign language recognition data.
7	Commercial Glove-Based System	is a means to handle the quandary of communication for deaf and mute individuals.
8	Non-Commercial Glove Sensor	is an electronic component, unit, or subsystem that distinguishes hand movements or changes in finger bending and sends data to other electronic devices, often to a computer processor.
9	Bi-Channel Sensor-Based System	is a mean for hand posture recognition based on data fusion of multi-channel electromyography (EMG) and inertial sensors.
10	Criterion Importance	is the significant criteria that present varying measurements and values from one to another, which considers the major issue in any evaluation and benchmarking in relative studies.

(continue)

Table 1.1 *(continue)*

Number	Terminology	Definition
11	Conflict Criterion	is the indication of the criteria values when they will not appropriately have additional or high criteria values, which is an issue when there is a conflict between few criteria values considered in the process of the evaluation and benchmarking.
12	Multi Criteria Decision Making	is a process of determining the best feasible solution according to established criteria and problems that are common occurrences in everyday life.
13	Multi Attribute Decision Making	is a making preference decisions approach under MCDM (such as evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes.
14	Multiple Objective Decision Making	is a making preference decisions approach under MCDM to plan/design the most suitable alternative with respect to limited resources.
15	Special Education Centers	is a school catering for students who have special educational needs due to learning difficulties, physical disabilities, or behavioural problems.
16	Likert Scale	is a unidimensional scale that researchers use to collect respondents' attitudes and opinions.
17	Systematic Ranking	is an assessment procedure of evaluation process to validate a newly obtained results from applying newly proposed methods in different fields.

1.9 Research Organization

This research is composed of three chapters. These chapters are briefly reviewed as follow:

Chapter 1 provides an introduction and followed by the research background. Moreover, this chapter demonstrates the research problem or problem statement. Furthermore, the research questions and followed by the research objectives discussed in this chapter. This chapter also presents the research scope and research significant of the study.

Chapter 2 provides a review for the SLRSs by covering the essential elements related to sign language gesture formation and Sign language recognition approaches. This chapter also examines and reviewed the sensor based SLRSs also reviewed by covering the development. Moreover, open issues of evaluation and selection SLRs are presented. This chapter ends with analyses to the research problems and highlights what should be done to solve those problems.

Chapter 3 gives the full description for the first part of the research methodology, which consists of four phases, namely, preliminary study phase, identification phase, formulation phase for the PFDOSM-IHAM method and its extension IVP-FDOSM and evaluation phase. Each phase corresponds and addresses to one or more research objectives.

Chapter 4 presents and discusses the results of the proposed PFDOSM-IHAM method and its extension IVP-FDOSM which are used in the multidimensional evaluation and benchmarking of real-time SLRSs. Moreover, the individual and group decision-making contexts are presented and used to achieve the research aim. The evaluation results of the proposed real-time SLRS decision matrix are illustrated. Afterwards, the opinion and fuzzy opinion matrices followed by individual and group benchmarking results are achieved and presented. Moreover, the evaluation process in detail for the results of the multidimensional evaluation and benchmarking to the real-time SLRSs based on PFDOSM-IHAM method and its extension IVP-FDOSM is presented on this chapter. The process of the evaluation was crucial for various empirical studies to prove the accuracy and validity of results. Thus. the multidimensional evaluation and benchmarking results of SLRSs achieved by PFDOSM-IHAM method and its extension IVP-FDOSM are evaluated on the basis of two assessment procedures, which are the systematic ranking evaluation and a comparing the proposed PFDOSM-IHAM method and its extension IVP-FDOSM with other relevant MADM methods.

Chapter 5 highlights a summary of the main findings and contributions, claim points, limitations, and future work, of this research. Moreover, the research goals attained, research claim points, and the research contribution have been described. Furthermore, the research limitations and the recommendations for future work are elaborated. Finally, the research conclusion is presented.

1.10 Chapter Summary

This chapter provides a background about the SLRS. In the statement of the problem, the SLRSs evaluation and benchmarking determined as a complex decision-making problem with multiple available systems. The main goal of this research is to provide a method using MADM for evaluation and benchmarking process, and the specific objectives are also discussed. Research questions of this study are listed in this chapter. Moreover, this chapter presented the benefits and significant of this research, which are organized into three categories according to related benefits. The final part of this chapter presented the general idea of the other chapters of this research.