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HYBRID NUMERICAL ASSIGNMENT AND ANALYTICAL HIERARCHICAL PROCESS

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ABSTRACT

Nowadays, the whole world based on software to manage the huge jobs, as results of this, the software became very complex and need systematic way to build them. Therefore, choosing the right requirements from candidate requirements is one of the important steps in software engineering and provide project planning phase with good decisions this is requirement Prioritization. In this paper, we propose hybrid technique of numerical assignment and analytical hierarchical Process to solve requirement prioritization problem at which numerical assignment collect the requirements into different groups as first step, then reciprocal matrix of requirements is developed by analytical hierarchical process and used to compare every pair of requirement of each group with respect to number of criteria. We compare and analyze proposed technique with numerical assignment and analytical hierarchical Process in term of time, number of comparison, number of requirements, scalability, granularity, accuracy, speed and complexity in prioritization process. The results show that proposed technique outperformed on AHP technique by number of requirements, complexity, number of comparison, scalability and speed whereas outperformed on numerical assignment by accuracy and granularity.

Keywords: *Numerical Assignment, Analytical Hierarchical Process, Requirement Prioritization*,

1. INTRODUCTION

Building a new software is complex task. The development of a detailed study of requirements prioritization (RP) is necessary to give value to the customers' business and making the product competitive in the market. For this purpose, criteria such as benefits, cost, risk and time should be considered. The competitive software requires careful planning, which incorporates a requirements prioritization process. There are numerous prioritization techniques which can be divided to nominal, ordinal, and ratio scales. These scales have common characteristics which shared by prioritization techniques belong to it. The nominal scale distributes the requirements to groups specified in advance whereas ordinal and ratio scales produce ordered list of requirements where each requirement assigned unique priority, for example in ordinal scale the requirements ordered according to priority beginning from 1 as a most important to the n as a least important where n is the number of requirements. But the difference between ordinal and ratio scales is that ratio makes each requirement have the relative difference respect to others requirements [1, 2].

The requirement prioritization is achieved by different techniques that belong to different scales such as MoSCoW [3,4] and Numerical Assignment(NA) [5] that involved in nominal scale. Whereas Bubble Sort Technique [5], Quality Function Deployment [6, 7], Ranking [8], Planning game [9,10,11], and Binary Search Tree [12] are involved in ordinal scale and Hundred Dollar(points) [13,14], Analytical Hierarchical Process (AHP) [6, 15, 16], Interactive Genetic Algorithm [17], and Value Oriented Prioritization [18] are belonged to ratio scale. These techniques play an important role in software development which guides the developer to concentrate on the features that are most important for building the system [19].

The requirement prioritization process produces short list of important requirement from large set of requirements these features are essential and should be delivered immediately to the customer and the rest of the requirements can be delayed for later increments. By using these techniques to extract the high priority requirements and implemented it first, this lead to save cost, time and make the customer satisfied [19].

The short list of important requirement based on many factors to being generated. The factors

involves complexity, cost, risk, scalability, contradictory, sensitivity against errors, stakeholder expectations, constraints, dependencies, volatility, resources, speed,, time, empirical validation, ease to use, support for consistency index effort, approach type, result type, punishment, size of requirements, granularity, sophistication, perspective, expert biases, type of technique (manual or algorithmic), number of comparisons, structure, customer importance, strategic and integrity strategic importance, customer satisfaction, marketing , provision of change of requirements, sales impact [8,20-28].

Because requirements prioritization is a significant part of software engineering which helps to make good decisions regarding project planning and implementation with preferred requirements [29, 30, 31] and because systems sometimes have useless functions for the users and customers where large amount of the software functions are rarely used (19%) or never used (45%) [32], the hybrid technique is proposed to enhance requirements prioritization process.

In this paper, the hybrid method is proposed to exploit the good characteristics of both nominal and ratio scales and overcome on bad properties of both them. The nominal scale is represented by numerical assignment and analytical hierarchical Process as technique of ratio scale. The proposed technique work by applying numerical assignment on requirements to distribute them on the groups prepared in advance and then prioritizing the requirements of each group by AHP technique. The proposed technique was analyzed and compared with numerical assignment and analytical hierarchical Process in term of time, number of comparison, number of requirements, scalability, granularity, accuracy, speed and complexity in prioritization process.

The remainder of this paper is organized as follows: Requirements prioritization scales from the literature are introduced in Section 2. The AHP technique is presented in Section 3. The numerical assignment techniques is presented in Section 4. The proposed technique is presented in Section 5. The case study is used to be applying by AHP, NAT and the proposed technique is presented in Section 6. Then analysis and discussion of the results is presented in Section 7. Finally, Section 8 concludes this paper.

2. RELATED WORK

Requirements prioritization (RP) with high number of requirements can be more difficult to prioritize so that the used technique should be selected carefully to meet user needs. RP process results depend on the scale and technique which in use. The several researchers in this domain proposed hybrid techniques to enhance the process results in many term such as accuracy, scalability, and number of requirements. Abou-Elseoud et al. in [33] proposed hybrid technique which combined by both of cumulative voting and decision-weighted matrix techniques. Its results achieve clarity, simplicity and efficacy of the proposed technique after applying on illustrative multiple goals example.

Dabbagh and Lee [34] developed a new technique which aims to integrate prioritizing functional and nonfunctional requirements. The outcome of applying the proposed technique, two distinct prioritized lists of functional and non-functional requirements. The proposed technique has been evaluated through an empirical experiment by comparing it with analytic hierarchy process (AHP) and hybrid assessment method (HAM). Results of their technique show that proposed approach better than AHP and HAM in terms of actual time-consumption.

Mead [35] applied AHP on case study by comparing the requirements as pairwise, he set reciprocal matrix and comparing every pair of requirement with respect to number of criteria.

Danesh and Ahmad [36] applied numeral assignment and AHP techniques by students as subjects to prioritize requirements from a library information system and an estate agency system. Two groups of students, one from requirements engineering classroom and another group consists of research students participate in the study. Based on numeral assignment, they suggest that requirements should be classified as mandatory (the customer cannot do without it), desirable (the customer would appreciate it, the customer would accept its absence), or inessential (Does not matter). Whereas in AHP, they compare the candidate requirements as pair-wise to estimate their relative importance.

In [38] the authors presented a framework that will help software engineer to prioritize the requirements by combining existing techniques and approaches, they use 100 hundred, AHP, B-tree and Numerical Assignment, the framework could be used to prioritize requirements that are small, medium and large in number, this framework need to be tested in real scenarios.

3. THE ANALYTICAL HIERARCHY PROCESS (AHP) TECHNIQUE

The Analytical hierarchical process (AHP) is a several criteria decision maker which based on the pairwise comparison approach to prioritize requirements. The requirements are compared pair-

wise to evaluate their relative importance by reciprocal matrix [15, 16, 36]. It can prioritize little number of requirement while in software development life cycle contains thousands of requirements which making very complex for this technique to deal with. Because it makes a large number of comparisons and repeated checking of consistency ratio which add extensive effort for decision maker. It has other disadvantages which are time consuming vagueness and poor scalability. The total number of comparison is n(n-1) \2 where n is the total number of requirement [6].

The relative importance of each requirement can be calculated by calculating the eigenvalues of the resulting comparison matrix. The eigenvalues represent the priorities of each of the requirement [37]. Since AHP technique is based on a ratio scale, this means that the requirements' priorities always add up to 100% [36].

4. THE NUMERICAL ASSIGNMENT TECHNIQUE

Numerical Assignment suggests that requirements should be collected in priority groups such as mandatory, desirable, and inessential groups [36]. Each group representing something stakeholders can relate to. In order to do not be all candidate requirements in one group by stakeholders, the maximum percentage of requirements that can be placed in each group should be defined. The requirements in each group have the same priority with no unique priority allocated per requirement [5].

5. THE PROPOSED HYBRID REQUIREMENTS PRIORITIZATION

The requirement prioritization techniques are classified into different scales , each scale has a common characteristics some of these characteristics consider as a strength , other consider as drawbacks ,so that choosing the convenient technique that satiety the stakeholder expectation is a difficult job, because using one technique will not give the best result, from previous literature .we note that there are three types of scales nominal ,ordinal ,and ratio scale we study and analyze these scales and find out that by combining two technique from different scales , the efficiency of new technique is improved , so we choose numerical assignment from nominal scale and AHP from Ratio scale so as to combine them and form a new technique in which the output of numerical assignment will be the input of AHP , the functionality of the proposed scheme is as follows:

1. We define all the candidate requirements for the project with assumption to have nine requirements.

2. By using Numerical Assignment we prioritize the candidate requirements and divide it into three different groups, and each group have 3 requirements as follows:

- Mandatory which include the requirement that must be included in the project and it is very important to the system.
- Desirable group which include the requirements that should be included in the project and it is rather important to the system.
- Inessential group which include the requirements that does not matter to be in the project and it's not important to the system.

3. After distributing the requirements into three groups the requirement priority in each group is the same and the priority of the Mandatory is more than desirable and desirable of course more than inessential group.

4. The output of this technique is course grain, low accuracy but scalable, fast and can deal with large no of requirements.

5. So as to overcome the disadvantage of NA we have to prioritize the requirement in each group to make it more accurate and fine grain.

6. We use AHP to prioritize the requirements in each group.

7. The principle of the AHP technique is to compare the requirements in pairwise by creating a matrix of n x n where n is the number of requirements and insert n in the rows and columns of the matrix.

8. Do pairwise comparison between requirements in which the no of comparison= n (n-1)/2, the scale weight which is used for comparison is given below in table 1.

9. Normalize the values in the matrix to estimate the given values by finding the summation of the n columns in the comparison matrix, then divide each element by the sum of every column for which that element is a member.

10. From the normalized matrix we obtain the overall or final priorities by calculating the average value of each row.

11. We calculate the consistency to make sure that our work is accurate.

12. Figure.1 shows the functionality of the proposed scheme.

Table.1 satty's pairwise comparison scale.

Intensity of importance	Definition
1	Equally important
2	Equally or slightly more important
3	Slightly more important
4	Slightly to much more important
5	Much more important
6	Much to far more important
7	Far more important
8	Far more important to extremely more important
9	Extremely

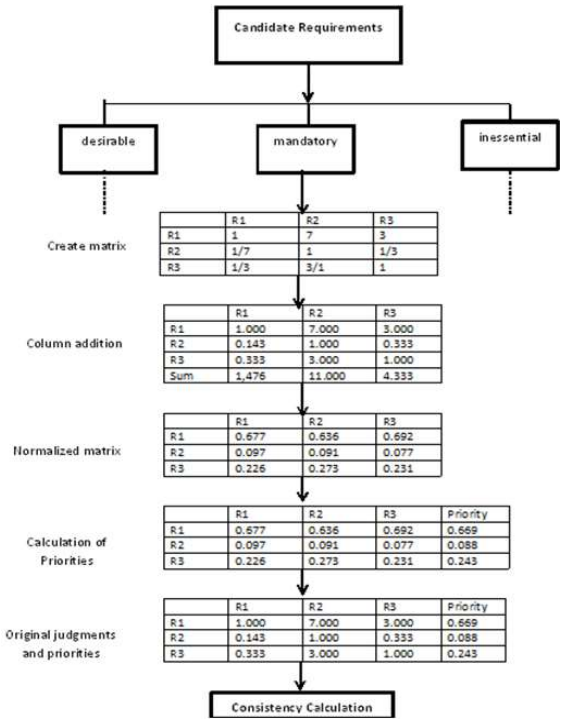

Fig.1 The functionality of the proposed scheme

6. CASE STUDY

Project: design a patient information system to support dental clinic which maintain information about patients whom treated in the clinic, the system makes use of a centralized database. The key features of the system are:

1. Registration. The system shall create records for patients and store it in a database.
2. Appointments. The system shall schedule and keep appointment for the patients.
3. Diagnosis and Treatment. The system shall record diagnosis and treatment of the patient.
4. The system shall display and print treatment fees.
5. The system should support search, creation of reports, and backup database.
6. The system should display the number of treated patient per day.
7. The system should display the patient history record.
8. The system should register the medicine prescribed to the patient by the doctor.

From previous case study the system requirements are: R1 registration, R2 Appointments, R3 diagnosis and treatment, R4 treatment fees, R5 search, R6 create report, R7 backup database, R8 treated patients, R9 patient history records, R10 medicine prescribed. There were no specified conditions under which the study was carried out, therefore it can be used and valid to prioritize any requirements. The proposed technique is evaluated according to some factors like accuracy, speed, number of requirements, complexity, number of comparison, scalability which are the most significant factors in requirement prioritization.

6.1 Application of the Numerical Assignment Technique (NAT) in the case study.

According to NAT we have three groups mandatory group in which we put the essential requirements for the system, desirable group in which we put the moderate important requirements for the system, inessential group in which we put the less important requirements for the system.

So applying that in the case study we have the following groups with their requirements:

1. Mandatory group
   - Registration (R1).
   - Appointment (R2).
   - Diagnosis and Treatment (R3).
   - Treatment fees (R4).
2. Desirable group.
   - Search (R5).
   - Create report (R6).
   - Back up data base (R7).
3. Inessential group.
   - Treated patients (R8).
   - Patient history record (R9).
   - Medicine prescribe (R10).

6.2 Application of AHP in the case study.

First we create a comparison matrix. (n = 10, no of comparison =45)

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1. Create the matrix

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R1	1	3	2	4	5	7	9	8	6	9
R2	1/3	1	1/2	2	3	5	6	6	4	7
R3	1/2	2	1	3	5	6	7	8	5	9
R4	1/4	1/2	1/3	1	2	3	4	5	2	3
R5	1/5	1/3	1/5	1/2	1	1	2	3	2	3
R6	1/7	1/5	1/6	1/3	1	1	2	3	1/2	2
R7	1/9	1/6	1/7	1/4	1/2	1/2	1	1/3	1/5	1
R8	1/8	1/6	1/8	1/5	1/3	1/3	3	1	1/6	2
R9	1/6	1/4	1/5	1/2	1/2	2	5	6	1	3
R10	1/9	1/7	1/9	1/3	1/3	1/2	1	1/2	1/3	1

2. Then we compute the sum of each column.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R1	1	3	2	4	5	7	9	8	6	9
R2	0.333	1	0.5	2	3	5	6	6	4	7
R3	0.5	2	1	3	5	6	7	8	5	9
R4	0.25	0.5	0.333	1	2	3	4	5	2	3
R5	0.2	0.333	0.2	0.5	1	1	2	3	2	3
R6	0.143	0.2	0.167	0.333	1	1	2	3	0.5	2
R7	0.111	0.167	0.143	0.25	0.5	0.5	1	0.333	0.2	1
R8	0.125	0.167	0.125	0.2	0.333	0.333	3	1	0.167	2
R9	0.167	0.25	0.2	0.5	0.5	2	5	6	1	3
R10	0.111	0.143	0.111	0.333	0.333	0.5	1	0.5	0.333	1
SUM	2.94	7.76	4.779	12.12	18.67	26.33	40	40.83	21.2	40

3. We normalized the matrix by divide each cell by the total of the column

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R1	0.3401	0.3866	0.4185	0.3301	0.2679	0.2658	0.2250	0.1959	0.2830	0.2250
R2	0.1134	0.1289	0.1046	0.1651	0.1607	0.1899	0.1500	0.1469	0.1887	0.1750
R3	0.1701	0.2577	0.2093	0.2476	0.2679	0.2278	0.1750	0.1959	0.2358	0.2250
R4	0.0850	0.0644	0.0698	0.0825	0.1071	0.1139	0.1000	0.1224	0.0943	0.0750
R5	0.0680	0.0430	0.0419	0.0413	0.0536	0.0380	0.0500	0.0735	0.0943	0.0750
R6	0.0486	0.0258	0.0349	0.0275	0.0536	0.0380	0.0500	0.0735	0.0236	0.0500
R7	0.0378	0.0215	0.0299	0.0206	0.0268	0.0190	0.0250	0.0082	0.0094	0.0250
R8	0.0425	0.0215	0.0262	0.0165	0.0179	0.0127	0.0750	0.0245	0.0079	0.0500
R9	0.0567	0.0322	0.0419	0.0413	0.0268	0.0759	0.1250	0.1469	0.0472	0.0750
R10	0.0378	0.0184	0.0233	0.0275	0.0179	0.0190	0.0250	0.0122	0.0157	0.0250

4. calculate the priority or (score) by taking the average of each row.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Priority
R1	0.3401	0.3866	0.4185	0.3301	0.2679	0.2658	0.2250	0.1959	0.2830	0.2250	0.2938
R2	0.1134	0.1289	0.1046	0.1651	0.1607	0.1899	0.1500	0.1469	0.1887	0.1750	0.1523
R3	0.1701	0.2577	0.2093	0.2476	0.2679	0.2278	0.1750	0.1959	0.2358	0.2250	0.2212
R4	0.0850	0.0644	0.0698	0.0825	0.1071	0.1139	0.1000	0.1224	0.0943	0.0750	0.0915
R5	0.0680	0.0430	0.0419	0.0413	0.0536	0.0380	0.0500	0.0735	0.0943	0.0750	0.0578
R6	0.0486	0.0258	0.0349	0.0275	0.0536	0.0380	0.0500	0.0735	0.0236	0.0500	0.0425
R7	0.0378	0.0215	0.0299	0.0206	0.0268	0.0190	0.0250	0.0082	0.0094	0.0250	0.0223
R8	0.0425	0.0215	0.0262	0.0165	0.0179	0.0127	0.0750	0.0245	0.0079	0.0500	0.0295
R9	0.0567	0.0322	0.0419	0.0413	0.0268	0.0759	0.1250	0.1469	0.0472	0.0750	0.0669
R10	0.0378	0.0184	0.0233	0.0275	0.0179	0.0190	0.0250	0.0122	0.0157	0.0250	0.0222

5. We present the result with the original judgments and priorities

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Priority
R1	1	3	2	4	5	7	9	8	6	9	0.2938
R2	1/3	1	1/2	2	3	5	6	6	4	7	0.1523
R3	1/2	2	1	3	5	6	7	8	5	9	0.2212
R4	1/4	1/2	1/3	1	2	3	4	5	2	3	0.0915
R5	1/5	1/3	1/5	1/2	1	1	2	3	2	3	0.0578
R6	1/7	1/5	1/6	1/3	1	1	2	3	1/2	2	0.0425
R7	1/9	1/6	1/7	1/4	1/2	1/2	1	1/3	1/5	1	0.0223
R8	1/8	1/6	1/8	1/5	1/3	1/3	3	1	1/6	2	0.0295
R9	1/6	1/4	1/5	1/2	1/2	2	5	6	1	3	0.0669
R10	1/9	1/7	1/9	1/3	1/3	1/2	1	1/2	1/3	1	0.0222

6. We calculate the consistency Ratio CR= CI/RI where CI is the consistency index, RI is the index of random-like matrix, CI = (λmax – n)/(n-1) = (11.195-10)/(10-1) = 0.1327 , λmax calculated for the previous case study which =11.195 , CR= CI/RI = 0.1327/1.51 =0.08 ,where RI = 1.51 for n=10.Since CR less than 0.1 so the matrix is consistence.

6.3 Application of the proposed scheme in the case study.

1. The requirements are divided into 3 group mandatory, desirable, inessential using Numerical Assignment technique
2. We apply AHP to prioritize the requirements in each group and the results are as follows:

- **Mandatory group**. (n = 4, no of comparison =6)

1.We create the matrix

	R1	R2	R3	R4
R1	1	3	2	4
R2	1/3	1	1/2	2
R3	1/2	2	1	3
R4	1/4	1/2	1/3	1

2. We find the sum of each column

	R1	R2	R3	R4
R1	1	3	2	4
R2	0.3333	1	0.5	2
R3	0.5	2	1	3
R4	0.25	0.5	0.3333	1
sum	2.0833	6.5	3.8333	10

3. We normalize the matrix

	R1	R2	R3	R4
R1	0.4800	0.4615	0.5217	0.4000
R2	0.1600	0.1538	0.1304	0.2000
R3	0.2400	0.3077	0.2609	0.3000
R4	0.1200	0.0769	0.0870	0.1000

4. Find the priority by averaging each row

	R1	R2	R3	R4	priority
R1	0.4800	0.4615	0.5217	0.4000	0.4658
R2	0.1600	0.1538	0.1304	0.2000	0.1611
R3	0.2400	0.3077	0.2609	0.3000	0.2771
R4	0.1200	0.0769	0.0870	0.1000	0.0960

- **Desirable group**. (n = 3, no of comparison =3)

1.Create the matrix

	R5	R6	R7
R5	1	2	2
R6	1	1	2
R7	1/2	1/2	1

2. Find the sum of each column

	R5	R6	R7
R5	1	2	2
R6	1	1	2
R7	0.5	0.5	1
SUM	2.5	3.5	5

3. Normalize the matrix

	R5	R6	R7
R5	0.4	0.4	0.4
R6	0.4	1	0.4
R7	0.2	0.5	0.2

4. Find the priority

	R5	R6	R7	priority
R5	0.4	0.4	0.4	0.4
R6	0.4	1	0.4	0.6
R7	0.2	0.5	0.2	0.3

- **Inessential group.** (n = 3, no of comparison =3)

1. Create the matrix

	R8	R9	R10
R8	1	1/6	2
R9	6	1	3
R10	0.5	1/3	1

2. Find the sum of each column

	R8	R9	R10
R8	1	0.1667	2
R9	6	1.0000	3
R10	0.5	0.3333	1
SUM	7.50	1.5000	6

3. Find the priority

	R8	R9	R10	priority
R8	0.1333	0.1111	0.3333	0.1926
R9	0.8000	0.6667	0.5000	0.6556
R10	0.0667	0.2222	0.1667	0.1519

7. ANALYSOIS AND DISCUSSION

By analyzing Table 2, the proposed technique is able to outperform AHP and numerical assignment in term of the following:

A. Speed. The speed of the proposed technique is higher than others. The proposed technique can prioritize the requirements in each group independently of other groups by AHP technique after numerical assignment applied.

B. The No. of comparison of proposed technique is less than others. In AHP technique, number of comparison = n (n-1)/2. And No. of comparison in numerical assignment techniques are low. Based on the case study, there are three groups in which the first group contains 4 requirements, the second group includes 3 requirements and the last groups contains 3 requirements. AHP will take 12 comparisons to prioritize all requirements in each group rather than 45 comparisons as single group.

C. Accuracy. The proposed technique is algorithmic and depend on computation so it is accurate such as AHP technique.

D. No. of requirements: AHP technique is fit to medium or small number of requirements, and the same for ordinal scale, while the proposed technique can deal with large number of requirements after dividing them on different groups.

E. Scalability: Scalability in AHP technique is low while in numerical assignment are medium. The proposed technique can be more scalable since it based on groups where each group is independent on others.

F. Granularity: The proposed technique can ensure fine prioritization to requirement.

G. Complexity: AHP technique considered as complex technique according to literature, whereas Numerical assignment based on simple steps. The proposed technique can simplify the prioritization of requirements by reducing number of requirements in each group.

H. When compared to the literature, our proposed technique outperforms articles [35] [38] in terms of speed and computation overhead, since article [35] used AHP, which requires a lot of comparisons, that increases computation overhead, and article [38] used multiple stages in his framework, which increases computation overhead. Our proposed technique also outperforms article [36], which uses numerical assignment, in terms of accuracy.

8. CONCLUSION

This paper proposed a technique which based on numerical assignment and AHP techniques to prioritize requirements by dividing the requirements to different groups based on numerical assignment technique and then applying AHP technique on each group independently. The strengths of the proposed technique include reducing the computation overhead by decreasing the number of comparison which make it fast, increasing the number of requirements that can deal with, enhancing the accuracy since it is algorithmic and depend on computation, it is also scalable since we can add new requirements easily, the complexity is simplified by dividing the requirements into groups.

The proposed technique outperformed AHP in term of number of comparison and computation overhead whereas outperformed numerical assignment by accuracy and granularity.

Table.2 The comparative results of the proposed technique against AHP and numerical assignment techniques

Technique	Speed	Complexity	Accuracy	Granularity	No of requirement	No. of comparison	Scalability
AHP	Slow	Complex	Accurate	Fine	Small	High	Not Scalable
Numerical assignment	High	Easy	Less accurate	Course	Medium	Low	Scalable
Proposed technique	High	Average	Accurate	Fine	Large	Low	Scalable

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