Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 86 (2015) 35078-35085

ISSN: 2229-712X

Uncertainty of measurement :Literature review

N.K.Mandavgade[1,*], S.B.Jaju[2] and R.R.Lakhe[3]

[1]Priyadarshini college of Engg, Nagpur, Maharashtra, India.
[2]G.H.Raisoni College of Engg, Nagpur, India.
[3]Shreyas Quality Management System, Nagpur, Maharashtra, India.

ARTICLE INFO

Article history:
Received: 22 June 2015;
Received in revised form:
4 September 2015;
Accepted: 14 September 2015;

Keywords
Uncertainty of measurement,
Sources of variations,
Errors,
GUM,
Montecarlo,
Material testing,
Chemical testing,
Modeling techniques.

ABSTRACT

Uncertainty of measurement has attracted more researchers in recent past. In this paper ,an attempt is made to review the status of literature in measurement uncertainty. The uncertainty of measurement is related to measurement and calibration process only. A very few literature are available related to uncertainty of measurement. A literature classification scheme is suggested. A number of articles from referred international journals and international conferences are classified based on various methodology (GUM, analytical approach and montecarlo approach etc). The paper shows the country wise awareness in the field of uncertainty. The gap in the research are identified along with the scope of UOM in various application.

Introduction

Uncertainty of measurement has attaracted more researchers in recent past. In this ,an attempt is made to review the status of literature in measurement uncertainty based on various criteria. The uncertainty of measurement is related to measurement and calibration process. A literature classiffication scheme is suggested. The number of articles from referred international journals and international conferences are classified based on various methodologies. The literature shows the country wise awareness in the field of uncertainty. The gap in the research on uncertainty of measurement are discussed.

This paper provides an extensive literature review on uncertainty of measurement. This paper outlines the following:

1. Define what constitute uncertainty of measurement (UOM)research.
2. Classification of UOM research articles according to their application and methodologies applied.
3. Exploration of trends in UOM research and suggest the research agenda for future work

Source of Literatures

Numberous articles dealing with theory and application of UOM have been published over last 20 years ,but topic is still under considerable developement and debat. We examine the work related to UOM published in referred journals. The numbers of articles from reputed journals like measurement by Elsevier etc, international conferences and symposium have been reviewed. The distributions of articles in various journals are given in table 1.

UOM applied in various fields

The concept of UOM is applied in various fields of application, calibration, as well as measurement and decision making process. The reviewed literatures are classified on the basis of application as shown in table 2 and table 3. The literature shows that maximum work is related to the mechanical application and basic terminologies are as shown in figure 1.

UOM in Calibration of instruments

The UOM is basically used in the calibration of instruments. Doiron and Stoup (1997) explained that every measurement produces only an estimate of the answer, the primary requisite of an uncertainty statement is to inform the reader of how sure the writer that the answer is in certain range. His report explains implementation of these rules for dimensional calibrations of nine different types of gages: gage blocks, gage wires, ring gages, gage balls, roundness standards, and optical flats indexing tables, angle blocks, and sieves.

Dahlberg (2010) reviewed measurement uncertainty associated with the calibration and use of modern materials testing machines. Dahlberg discusses, the effect of calibration uncertainties on test data produced by materials testing machines and measurement uncertainty related to ISO calibration practices. Megahed and Abdelaziz (2011) reviewed that the previous studies of the Pt/Pd thermocouples at NIS-Egypt, shows promise of achieving significant improvements in uncertainty of temperature measurements up to 960 °C. Megahed and Abdelaziz described the uncertainty assessment on the measurements of calibration of Pt/Pd thermocouples at fixed point cells up to freezing point of copper and by comparison technique following a defined heat treatment at 1100 °C.

UOM in mechanical field

The uncertainty of measurement is used in mechanical measurement on great extend. Donalson (1973) calculated the UOM in mass measurement. He stated that in many measurement processes, the mass of the unknown is not determined directly against a standard, but is measured indirectly through a chain of difference measurements. Jacoby (1994) explained, the impact of item-by-item information accessing on uncertainty reduction under self-selected and

Tele:
E-mail addresses: nkmandavgade@gmail.com

researcher –constrained information accessing on the shop floor. Although limited in generalization ,his studies suggest that under most circumstances ,subjective uncertainty reduction is most likely to assume an accelerating or perhaps a linear shape especially for people employing within –options ,across-properties information –accessing strategy.

Balsam et al(1999) reviewed that there has been an increasing interest in suitable techniques for evaluating the uncertainties of measurement values yielded by CMMs. Among others, simulation techniques appear to suit the versatility of CMMs and to keep the CMM user involvement to a minimum. Papadopoulos and Yeung (2001) demonstrate UOM estimation in case of flow measurement using the Monte Carlo simulation method. Monte Carlo simulation has the ability to take account of partial correlated measurement input uncertainties. For correlated input measurements, the probability distribution of the result could be biased or skewed. These properties cannot be revealed using conventional methods.

Phillips (2003) estimated UOM in calibrated artifacts. Phillips shows despite several reviews of the experiment by

numerous experts, the source of the systematic error (bias) remains a mystery. Phillips puts two important issues for measurement. (1) To detect some systematic errors and appropriately account for them in the uncertainty statement. (2) In some unusual situations, additional information can result in an increase in the uncertainty of a quantity. Silva (2004) developed a methodology for determining the result of measurement concerning tensile mechanical properties and their respective uncertainties. Kandil (2009) discussed, the main differences and commonalities in current standards polices and their potential implications in the mechanical testing area.

Liang et al (2009) reviewed the application of UOM in rough set theory where accuracy and roughness are effective measures. They have some limitations when the lower/upper approximation of a set under one knowledge is equal to that under other knowledge. To overcome these limitations, Liang et al addresses the issues of uncertainty of a set in an information system and approximation accuracy of a rough classification in a decision table.

Clark (2010) explained the UOM in weight balance measurement along with measurement quality terminology i.e. "accuracy", "precision", "linearity", "hysteresis"," measurement uncertainty"(MU) and the various contributors to MU. It will also discuss the advantages and limitations of various methods for estimating MU. Alkhatib and Kutterer (2011) reviewed that one tool to deal with different distribution functions of the input parameters and the resulting mixed-distribution of the output quantities given through the Monte Carlo techniques. To evaluate the procedure of derivation and evaluation of output parameter uncertainties outlined in this paper, a case study of kinematic terrestrial laser scanning (k-TLS) have been discussed.

Gajghate (2011) reviewed the data for different size fractions with aerodynamic diameters of PM10 on glass fiber filter using 8-stage Andersen cascade impactor. Samples were extracted using microwave acid digestion, and analysis was performed by Direct Mercury Analyzer, DMA-80. Repeatability showed maximum contribution to uncertainty budget followed by calibration curve and volume of air. Ramnath (2011) estimated the limitation in the uncertainty analysis for a pressure balance is that no readily accessible uncertainty quantification framework for the distortion coefficient is present. As a result the uncertainty in a pressure balance's area at elevated applied pressures is typically underestimated in the absence of this uncertainty information. Ramnath firstly review the uncertainty formulation for a pressure balance generated pressure involving correlation effects in terms of an implicit multivariate matrix equation approach.

Laghi et al (2011) reviewed the process in development of new measurement and analysis methods applied to building materials and their performances. Gupta and Kumar (2012) reviewed that the viscosity scale is established by step up method, in which several master viscometers and standard liquids are used. Uncertainty in the determination of viscometer constant of a viscometer or the kinematic viscosity of standard liquid at a particular step is carried forward for subsequent steps. The expressions for uncertainty for viscometer constant of the viscometer and kinematic viscosity of the liquid in ^{n}th step have been derived.

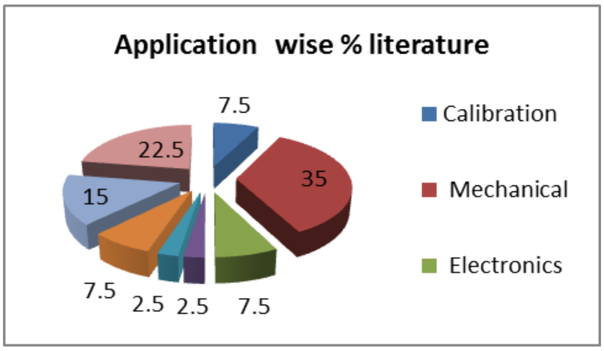

Figure 1. Application wise break up of literature

UOM in electronics field

The uncertainty of measurement is also a great application in the field of electronics measurement system. The numerous authors' works on different application such as Locci et al (2002) reviewed the uncertainty in measurement based on digital signal processing algorithms, like those achievable with the virtual instruments. Three possible approaches to this question are examined and compared. It is shown that how a Monte Carlo method, based on numerical simulations and implemented with commercial software packages, can allow virtual instruments to perform an auto-evaluation of both bias and uncertainty affecting their results.

Chimeno et al (2005) presents an easy way to explain this difficult concept of UOM that has been developed for electronic instrumentation students in the telecommunication engineering school of the Polytechnic University of Catalonia (Barcelona, Spain). Chimeno explained how to calculate type A and type uncertainty parameters in regards of some instrumentation. Otomański1 and Szlachta (2008) presented a possible application of integrated Lab VIEW environment to the final evaluation of measurement results in direct measurement. By using the Lab VIEW environment, we can support or add variety to the teaching of students in the field of metrology and measurement theory.

UOM in chemical field

The uncertainty of measurement is also a great application in field of chemical analysis. Horwitz and Albert (1997) reviewed that without a refinement of concepts, the metrologists risk losing a large part of their chemical constituency. The presentations of the metrologists suffer from a lack of clarity and transparency to a chemical audience. A more meaningful approach would replace the metrological ISO within-laboratory uncertainty by the more comprehensive analytical chemistry concept of among-laboratory reproducibility, the randomized individual laboratory biases combined with the pooled within-laboratory variability.

Table 1. Distribution of reviewed articles

A) Journal
Measurement science and Technology International Journal of Metrology and Quality Engineering
Journal of metrology society of India –Mapan
J. Res. Natl. Inst. Stand. Technology
Instrumentation and Measurement, IEEE Transactions
Measurement by Elsevier
Journal of Environmental Chemistry and Ecotoxicology
Accred Quality Assurance
Measurement science review Metrology and measurement system-Poland
International journal of instrumentation technology
International journal of measurement technologies & instrumentation
Analyst
Agricultural Engineering International: the CIGR Ejournal.
Metrologia
Res Eng Design
Information Sciences
Journal of consumer research
Int. J. Engg Ed.
European Journal of Operational Research
The Physics Teacher
The Science of the Total Environment
Integrated Assessment
Flow Measurement and Instrumentation
NBSIR,USA
B) International Conferences and symposium

Table 2. Application of UOM in various fields

Application	Authors
Calibration	Doiron and Stoup (1997), Dahlberg (2010) ,Megahed and Abdelaziz (2011)
Mechanical	Donalson(1973), Jacoby (1994), Balsam et al(1999), Papadopoulos and Yeung(2001), Phillips(2003), Silva(2004), Kandil(2009), Liang et a (2009), Clark(2010), Alkhatib and Kutterer(2011), Gajghate(2011), Ramnath(2011), Laghi et al (2011), Gupta and Kumar(2012)
Electronics	Locci et al(2002),Chimeno et al(2005), Otomański1 and Szlachta(2008)
Chemical	Horwitz and Albert(1997)
Electrical	Damasceno et al(2005)
Civil	Ramsey and Argyraki(1997), Dulal(2006), Ledda(2011)
Decision making	Howard Castrup(1995), Paulson and Zahir(1995), Smith(2002), Walker et al(2003), Weissensee et al(2005), Scott(2007)

Table 3. Application wise break up of literature

Focus on		Number of Papers	Percentage (%)
A)	Calibration	03	7.5
B)	Measurement Process-		
•	Mechanical	14	35
•	Electronics	03	7.5
•	Chemical	01	2.5
•	Electrical	01	2.5
•	Civil	03	7.5
C) Decision Making		06	15
D)Basic Terminology		09	22.5

Table 4. Development of literature on UOM

Sr.No	Reseachers	Year	Contribution to research
1	Donalson	1973	Identification and quantification of factors in mass measurement.
2	Jacoby et al	1994	Uncertainty reduction in multi item information system.
3	Castrup	1995	Uncertainty to decision risk in measurement.
4	Paulson and Zahir	1995	Uncertainty in analytical heirarchy process by simulation approache.
5	Doiron and Stoup	1997	Uncertainty in calibration of measuring instruments.
6	Ramsey and Argyraki	1997	Develope method for UOM in contaminated land.
7	Horwitz and Albert	1997	Develoed the concept for chemical measurement.
8	W. Tyler Estler	1997	Decide level of confidence in measurement.
9	Balsam et al	1999	Uncertainty calculation in CMM
10	Mauris	2001	Fuzzy approach used to calculate uncertainty of measurement.
11	Castrup	2001	Developed statistical distribution for errors and biases.
12	Papadopoulos and Yeung	2001	Explained the advantages of Monte carlo in UOM.
13	Smith	2002	Decision in risk assessment.
14	Locci et al	2002	Comparison of GUM, Analytical method and Monte Carlo for digitized data.
15	Walker et al	2003	Developed uncertainty matrix as a heuristic tool for analysts as well as between them and policymakers and stakeholders.
16	Phillips	2003	Develope the relation between uncertainty and tracebility.
17	Silva	2004	Developed a methodology for measurement concerning tensile mechanical properties and their respective uncertainties.
18	Castrup	2004	Developed model that for measurements where an attribute is measured directly and to multivariate measurements obtained by measuring various component quantities.
19	Ferrero	2004	Developed theory of the evidence and frames the random-fuzzy variables for UOM.
20	Damasceno et al	2005	Proved that monte carlo and ISO-GUM methods gives similar resultd for the Ag/AgCl electrode potential uncertainty (UE^o) determination used in Ph.
21	Weissensee et al	2005	Focus on economin consequences of incorrect decision caused bu measurement uncertainty.
22	Chimeno et al	2005	Explained the application of UOM to students in simpler form.
23	Cowen and Ellison	2006	Methodology for UOM and coverage interval near neutral limits.
24	Dulal	2006.	Develop framework for UOM applicable to the Bagmati River basin in Nepal.
25	Scott	2007	UOM in multicriteria decision making tool AHP using Monte carlo.
26	Kacker	2007	Discussed merits and limitations of GUM & GUM-S1
27	Buffler and Allie	2008	Consideration of UOM in physics laboartories .
28	Otomański1 and Szlachta	2008	Application of LAB VIEW for direct measuremet result in lab.
29	Kandil	2009	Discussed the main differences and commonalities in current standards polices ISO, CEN & ASTM.
30	Liang et al	2009	Developed new measure for uncertainty based of rough sets.
31	Dahlberg	2010	Stastical method for UOM due to errors in material testing Machine.
32	Clark	2010	UOM of Electronic weight balance .
33	Alkhatib and Kutterer	2011	UOM estimation of kinematic terrestrial laser scanning using Monte Carlo simulation.
34	Gajghate	2011	UOM using bottom –up-approach of glass fiber filter using 8-stage Andersen cascade impactor.
35	Ledda	2011	UOM of the inhibitory effect on Vibrio fischeri
36	Ramnath	2011	UOM of pressure balance using implicit multivariate matrix equation approach.
37	Laghi et al	2011	Uncertainty analysis of thermal conductivity measurements in material.
38	Megahed and Abdelaziz	2011	Uncertainty assessment of the calibration of Pt/Pd thermocouples at freezing point of copper.
39	Gupta and Kumar	2012	Derived expressions for uncertainty for viscometer constant of the viscometer and kinematic viscosity of the liquid.
40	Kosarevsky and Latypov	2012	Monte-Carlo error propagation is used to estimate the uncertainty of a position tolerance using least-squares criterion.

Table 5. Methodology used by various author for analysis of UOM

Methodology	Authors
Monte-Carlo	Paulson ,Zahir(1995), Balsam et al(1999), Papadopoulos and Yeung(2001), Smith(2002), Locci et al(2002), Damasceno et al(2005), Scott(2007), Alkhatib and Kutterer(2011), Kosarevsky and Latypov(2012)
Analytical method	Donalson(1973), Jacoby(1994), Horwitz and Albert(1997), Silva(2004), Castrup(2004), Cowen and Ellison(2006), Dulal(2006), Otomański1 and Szlachta(2008), Liang et a (2009), Dahlberg(2010), Clark(2010), Gajghate(2011), Ramnath(2011), Gupta and Kumar(2012)
ISO-GUM	Howard Castrup(1995), Doiron and Stoup (1997), Ramsey and Argyraki(1997), Estler(1997), Castrup(2001), Walker et al(2003), Phillips(2003), Weissensee et al(2005), Chimeno et al(2005), Kacker(2007), Buffler and Allie(2008), Kandil(2009), Ledda(2011),Laghi et al (2011), Megahed and Abdelaziz (2011)
Fuzzy approach	Mauris(2001), Ferrero (2004)

UOM in electrical field

The uncertainties of measurement are having applications in almost all fields. Damasceno et al (2005) compares the ISO-GUM approach and the Monte Carlo simulation method for the Ag/AgCl electrode potential uncertainty (UEo) determination used in pH uncertainty estimation in a phosphate solution at 25°C. The Monte Carlo simulation showed very similar results in comparison to the ISO-GUM approach. Damasceno et al proved that both methods are applicable for UEo determination and give reliable results.

UOM in civil application

The UOM in application of civil engineering fields are reviewed by different researchers. Ramsey and Argyraki (1997) devised the methods for estimating measurement uncertainties due to field sampling. The existing criteria for the classification of contaminated land generally depend on a deterministic comparison between measured concentration of a contaminated and a threshold level. A new probabilistic classification scheme proposed by Ramsey and Argyraki for contaminated land allows for the overall measurement uncertainty as well as the estimated concentration of the contaminant. Dulal (2006) aimed to develop a general framework for analyzing the uncertainty in precipitation measurement and to apply it as a case study to the Bagmati River basin in Nepal. Dulal used technique of enquiry lists, field survey and the assessment of dominant errors in precipitation measurement based on the field study. From the analysis of qualitative study, wind error is identified as a major source of error, followed by wetting error and evaporation error. The result of the quantitative analysis shows that the total error in precipitation for the basin is less than 15%. Ledda (2011) reviewed that the 11348-3:2007 ISO method allows the evaluation of the inhibitory effect of water samples on the light emission of Vibrio fischeri. Ledda propose a test with different 3,5-dichlorophenol dilutions to evaluate if the luminometer is functioning properly and suggest to consider the uncertainty contributions sum (xi), to calculate the standard deviation of reproducibility (SR) and, finally, to express the expanded uncertainty with the formula $U = 2SR + u(xi)$.

UOM in decision making

The decision making processes are affected by the various factors. Each parameter in decision making process plays vital role in case of economics as well as performance of the system. The uncertainties in every parameter affecting the decision process are studied by various authors. Howard Castrup (1995) explained how measurement decision risks are estimated based on the results of an uncertainty analysis example and risk management considerations are outlined. Paulson and Zahir (1995) reviewed a methodology for the propagation of uncertainty in the analytic hierarchy process (AHP). He explained that the sole source of the uncertainty is assumed to lie in the elements of the preference matrices. Smith (2002) reviewed that decisions in risk assessment are typically not crystal clear and hence there is uncertainty. Uncertainty analysis is the part of risk assessment that focuses on the uncertainties in the assessment. Walker et al (2003) aimed to synthesis a wide variety of contributions on uncertainty in model-based decision support in order to provide an interdisciplinary theoretical framework for systematic uncertainty analysis. Walker propose an uncertainty matrix as a heuristic tool to classify and report the various dimensions of uncertainty, thereby providing a conceptual framework for better communication among analysts as well as between them and policymakers and stakeholders.

Weissensee et al (2005) reviewed that error detected by an end user causes higher error-follow-up cost than error detected in subsequences stages of process. In order to gain an economic view of measurement uncertainty and risks of incorrect inspection decision, Weissensee et al stated that it is useful to review how different error sources in products have different costs associated with them. The advantage of procedure proposed by Weissensee et al is to weigh consequences of unnecessary efforts against the consequences of type II errors based on assessment error-follow-up cost. Scott (2007) offers a means to quantify how differently two alternatives must be ranked by AHP to instill confidence that one is truly better than the other. Scott quantified the uncertainty in AHP is from two distinct points of view. The first makes the assumption that AHP is structurally correct but subject to measurement ''error'' in the pair wise comparisons, while the second quantifies the uncertainties introduced by AHP's failure to consider different level of compensation in trade-offs among criteria.

Development in UOM research

In the last few years a lot of awareness has been created regarding uncertainty of measurement, due to mainly two reasons. First is laboratory accreditation, which has steadily been on the rise, requires estimation of uncertainty of measurement particularly in the field of calibration and testing. Secondly, increased maturity level of the quality system certification as the manufacturing companies looking at the reliability of measurement through correct calibration of measuring and test equipment. International and national regulations are required for testing and calibration laboratories to provide estimates of uncertainty with their measurements. In general, calibrations are incomplete without statements of the uncertainty in their estimate. The calculation of uncertainty for a measurement is an effort to set reasonable bounds for the measurement result according to standardized rules.

The concept of UOM is applied to calibration as well as measuring process. The developments in the field of measurement uncertainty process are shown in table 4

Methodologies in UOM

The various researchers have applied different methodologies for the estimation of UOM. The literatures are classified on the basis of methodology applied for the particular applications are given in table 5 and table 6. From the literature it is proved that GUM and analytical method are very popular in the field of UOM as shown in figure 2. As compare to fuzzy approach, Monte Carlo is also familiar in the field of UOM.

UOM using Monte-Carlo

The Monte Carlo simulation technique is popular for the estimation of UOM in particular applications. Paulson Zahir (1995) used ,simulation approache for estimating uncertainty in analytical heirarchy process. Balsam et al (1999) explained among others, simulation techniques appear to suit the versatility of CMMs and to keep the CMM user involvement to a minimum. Papadopoulos and Yeung (2001) demonstrate that the Monte Carlo simulation method is fully compatible with the conventional uncertainty estimation methods for linear systems and systems that have small uncertainties. Monte Carlo simulation is having advantages of taking into account partial correlated measurement input uncertainties. Smith (2002) reviewed that decisions in risk assessment are typically not crystal clear and hence there is uncertainty. Uncertainty analysis is the part of risk assessment that focuses on the uncertainties in the assessment using Monte Carlo. , Locci et al (2002) compared the uncertainty in measurement based on digital signal processing algorithms using three possible approaches. It is shown how a Monte Carlo method, based on numerical simulations and implemented with commercial software packages, can allow virtual instruments to perform an auto-evaluation of both bias and uncertainty affecting their results. Damasceno et al(2005) compares the ISO-GUM approach and the Monte Carlo simulation method for the Ag/AgCl electrode potential uncertainty (UEo) determination used in pH uncertainty estimation in a phosphate solution at 25oC. The Monte Carlo simulation showed very similar results in comparison to the ISO-GUM approach. Scott (2007) quantified the uncertainty in AHP using Monte Carlo approach. Alkhatib and Kutterer (2011) estimatated UOM of kinematic terrestrial laser scanning using Monte Carlo simulation. Kosarevsky and Latypov (2012) explained that determination of realistic uncertainty values in coordinate metrology is a challenging task due to the complexity of the implementation of numerical algorithms involved. Monte-Carlo error propagation is used to estimate the uncertainty of a position tolerance using least-squares criterion.

UOM using Analytical method

Donalson(1973)applied, analytical method for identification and quantification of factors in mass measurement. Jacoby (1994) proposed, uncertainty reduction in multi item information system using analytical apprach. Horwitz and Albert (1997) reviewed that without a refinement of concepts, the metrologists risk losing a large part of their chemical constituency. A more meaningful approach would replace the metrological ISO within-laboratory uncertainty by the more comprehensive analytical chemistry concept of among-laboratory reproducibility, the randomized individual laboratory biases combined with the pooled within-laboratory variability. Silva (2004) developed, a methodology for determining the result of measurement concerning tensile mechanical properties and their respective uncertainties using analytical method. Castrup (2004) presented a general measurement uncertainty model that can be applied to measurements in which the value of an attribute is measured directly and to multivariate measurements in which the value of an attribute is obtained by measuring various component quantities. Cowen and Ellison (2006) based on consideration of bias and simulation to assess coverage, suggested that the original standard uncertainty is retained for uncertainty propagation purposes using analytical method.

Dulal (2006) developed, a general framework for analyzing the uncertainty in precipitation measurement and to apply it as a case study to the Bagmati River basin in Nepal. Otomańskil and Szlachta (2008) presented, a possible application of integrated Lab VIEW environment to the final evaluation of measurement results in direct measurement by analytical method. Liang et a (2009) developed modified measure using analytical way for rough set theory where accuracy and roughness are effective measures. Dahlberg (2010) discusses the effect of calibration uncertainties on test data produced by material testing machines using analytical approach. Clark (2010) developed the methodology for estimation of UOM of weight measurement. Gajghate (2011) calculated uncertainty resulted due to sampling and analytical procedure by applying bottom-up approach for Direct Mercury Analyzer, DMA-80. Ramnath (2011) firstly review the uncertainty formulation for a pressure balance generated pressure involving correlation effects in terms of an implicit multivariate matrix equation approach. Gupta and Kumar (2012) developed uncertainty in the determination of viscometer constant of a viscometer or the kinematic viscosity of standard liquid.

UOM using ISO-GUM way

Howard Castrup (1995) explained, uncertainty to decision risk in measurement using GUM way. Doiron and Stoup (1997) estimated UOM in calibration of measuring instruments using GUM way and also stated that in many measurement processes, the mass of the unknown is not determined directly against a standard, but is measured indirectly through a chain of difference measurements. Ramsey and Argyraki (1997) proposed, a new probabilistic classification scheme for contaminated land, allows for the overall measurement uncertainty as well as the estimated concentration of the contaminant. Estler (1997) reviewed that the Bienayme-Chebyshev Inequality provides a quantitative bound on the level of confidence of a measurement with known combined standard uncertainty and assumed coverage factor. Castrup (2001) describes statistical distributions that can be applied to both Type A and Type B measurement errors and to equipment parameter biases using ISO-GUM approach. Walker et al (2003) proposed an uncertainty matrix as a heuristic tool to classify and report the various dimensions of uncertainty, for analysts as well as between them and policymakers and stakeholders. Phillips (2003) developed the relation between uncertainty and tracebility using GUM. Weissensee et al (2005) focused on economin consequences of incorrect decision caused by measurement uncertainty. Chimeno et al (2005) explained the GUM way of UOM to electoronic students in simpler form. Kacker (2007) discusses the new concepts introduced by the GUM and their merits and limitations. The limitations of the GUM led the BIPM Joint Committee on Guides in Metrology to develop an alternative approach—the draft Supplement 1 to the GUM (draft GUM-S1). Kacker discusses the draft GUM-S1 and its merits and limitations. Buffler and Allie (2008) focused, for designer and teacher of physics laboratories, about two things: how to make your laboratories relevant and interesting and how to reasonably deal with measurement errors using GUM approach. Kandil (2009) discussed the main differences and commonalities in current standards police ISO, CEN & ASTM. Ledda (2011) reviewed that the 11348-3:2007 ISO method allows the evaluation of the inhibitory effect of water samples on the light emission of Vibrio fischeri. Laghi et al (2011) described, the process in development of new measurement and analysis methods applied to building materials and their performances using GUM way. Megahed and Abdelaziz (2011) proposed significant improvements in uncertainty of temperature measurements up to 960 °C in the calibration of Pt/Pd thermocouples.

Table 6. Classification of Literature based on methodology applied

Methodology	Number of papers	Percentage (%)
Monte-Carlo	09	22.5
Analytical method	14	35
ISO-GUM	15	37.5
Fuzzy approach	02	5

UOM using fuzzy approach

Mauris (2001) explained with a fuzzy expression of uncertainty in measurement. This approach is compatible with the ISO Guide for the expression of uncertainty in measurement, and is particularly interesting because it allows both the handling of specificity and uncertainty of measurement. Ferrero (2004) reviewed that the probability theory is not the only tool to deal with distributions of values and is not the most suitable one when the values do not distribute in a totally random way. In this case, Ferrero proposed a more general theory, the theory of the evidence and frames the random-fuzzy variables within this theory, showing how they can usefully be employed to represent the result of a measurement together with its associated uncertainty. The mathematics is defined on the random-fuzzy variables, so that the uncertainty can be processed, and simple examples are given.

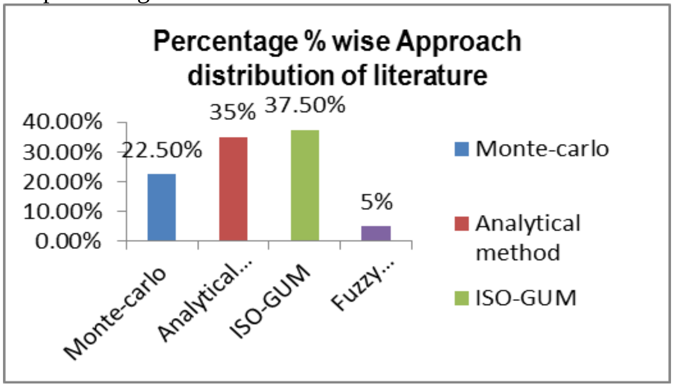

Figure 2. Application of approach used in UOM

Location wise awareness in field of UOM

In the era of globalization, market is totally open on the basis of selective assembly and interchangeability. All manufacturing industries are using ISO norms for manufacturing of the products, testing of the samples for various application are performed using UOM. The concept of UOM is used in all most all part of countries for calibration and testing purpose.

The literatures are classified on the basis of country wise contribution in the development of UOM is shown in table 7. From the literature reviewed as shown in figure 3, it is proved that the United States is having more awareness in the field of quality aspects and UOM. The growth of UOM in our developing country like India is very slow. Now awareness is continuously increasing towards laboratory accreditation and UOM.

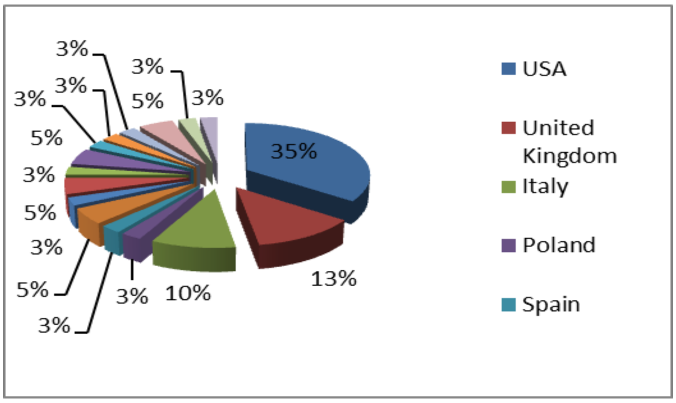

Figure 3. Countrywise development of UOM

Gaps in literrature research

The concept of UOM is like a black magic box. The ISO – GUM is the standard draft regarding the UOM. The work on measurement uncertainty has done by various researchers on different applications in various countries. But practically, there are a lot of confusions and difficulties in estimation of UOM.

The following are few research gaps in the literature

- The methodologies used by different authors are difficult to understand and to apply.
- The simplified and precise methodology for training and application purpose was not available.
- The effect of machine interference in case of multiple tests in the same laboratory was not considered earlier.
- The effects of qualitative factors such as operator, sample, and environmental conditions have not considered till date.

References

1. EURACHEM / CITAC guide CT4, quantifying uncertainty in analytical measurement second edition 2000.

2. Janet R. Donalson, “An Uncertainty in mass measurement”, NBSIR-73-151,Washington, DC. (USA) (1973).

3. Howard Castrup,“Uncertainty Analysis for Risk Management”, 1995 Measurement Science Conference, Anaheim, California(1995).

4. Dan Paulson and Sajjad Zahir (1995), “Consequences of uncertainty in the analytic hierarchy process: A simulation approach”, European Journal of Operational Research 87 pp. 45-56(1995).

5. Ted Doiron and John Stoup,“Uncertainty and Dimensional Calibrations”, Journal of Research of the National Institute of Standards and Technology, Volume 102,Number6,November–December1997,pp647-676(1997).

6. Ramsey and Argyraki, “Estimation of measurement uncertainty from field sampling: implications for the classification of contaminated land”, The Science of the Total Environment 198 pp 243-257(1997).

7. Horwitz and Albert, “The Concept of Uncertainty as Applied to Chemical Measurements”, Analyst, June 1997, Vol. 122 (pp 615–617) (1997).

8. W.Tyler Estler,“A Distribution-Independent Bound on the Level of Confidence in the Result of a Measurement”, J. Res. Natl. Inst. Stand. Technol. 102, pp 587(1997).

9. Balsam et al, “Evaluation of CMM Uncertainty Through Monte Carlo Simulations”, Annals of the CIRP Vol. 48/1/1999,pp 425-428(1999).

10. Gilles Mauris, “A fuzzy approach for the expression of uncertainty in measurement”, Measurement, Volume 29, Issue 3, April 2001, Pages 165–177(2001).

11. Howard Castrup, “Distributions for Uncertainty Analysis”, Presented at the 2001 IDW Conference, Knoxville, TN(2001).

12. Papadopoulos and Yeung, “Uncertainty estimation and Monte Carlo simulation method”, Flow Measurement and Instrumentation 12 ,291–298(2001).

13. Eric Smith, “Uncertainty analysis”, encyclopedia of Environmetrics (ISBN 0471 899976), Volume 4, pp 2283–2297(2002).

14. Locci et al, “ Evaluation of uncertainty in measurements based on digitized data”, Measurement 32 ,265–272(2002).

15. Walker et al, “Defining Uncertainty A Conceptual Basis for Uncertainty Management in Model-Based Decision Support,” Integrated Assessment, Vol. 4, No. 1, pp. 5–17(2003).

16. Phillips,“Measurement Uncertainty and Traceability Issues in National and International Measurements”, Presented at the International Dimensional Metrology Workshop, Nashville, TN ,May 12-16, 2003

17. Roberto and Silva, “Evaluation of the uncertainty of measurement of mechanical properties on the tensile testing”, Simposio de Metrología , 25 al 27 de Octubre, pp 1-5(2004).

18. Howard Castrup,“Estimating and Combining Uncertainties”, 8th Annual ITEA Instrumentation Workshop, Lancaster Ca.5 May 2004.

19. Ferrero, A, “The random-fuzzy variables: a new approach to the expression of uncertainty in measurement”, Instrumentation and Measurement, IEEE Transactions on ,53, Issue: 5, Page(s): 1370 – 1377(2004).

20. Damasceno et al, “Evaluation of Ag/AgCl-electrode standard potential uncertainty used in primary pH measurements by Monte Carlo simulation”, measurement science review, Volume 5, Section 2, 2005,pp.49-52.

21. Weissensee and Zinner, “Economic consequences of incorrect decision caused by measurement uncertainty-Assessment of risks and errors –follow up cost”, Joint

international IMEKO TC1+TC7 Symposium, September 21-24, 2005, Ilmenau, Germany.
22. Chimeno et al, "Teaching Measurement Uncertainty to Undergraduate Electronic Instrumentation Students", Int. J. Engg Ed. Vol. 21, No. 3, pp. 525-533(2005).
23. Cowen and Ellison, "Reporting measurement uncertainty and coverage intervals near natural limits", Analyst, 2006,131, PP.710-717(2006).
24. Dulal K.N. "A Framework for the Analysis of Uncertainty in the Measurement of Precipitation Data: a Case Study for Nepal", Agricultural Engineering International: the CIGR Ejournal. Manuscript LW 06 010. Vol. VIII. PP.1-16(2006).
25. Scott M.J, "Quantifying uncertainty in multi criteria concept selection methods", Res Eng Design 17:175–187, DOI 10.1007/s00163-006-0025-3(2007).
26. Kacker, "Evolution of modern approaches to express uncertainty in measurement", *Metrologia* 44 513 doi:10.1088/0026-1394/44/6/011(2007).
27. Buffler and Allie, "Teaching Measurement And Uncertainty The GUM Way", The Physics Teacher, Vol. 46,December2008,PP.539-543, DOI: 10.1119/1.3023655.
28. Otomański1 and Szlachta,"The Evaluation of Expanded Uncertainty of Measurement Results in Direct Measurements Using the Lab VIEW Environment", Measurement science review, Volume 8, Section 1, No. 6, ,PP.147-150(2008).
29. Kandil. "Measurement Uncertainty in Material Testing: Differences and Similarities between ISO, CEN and ASTM Approaches", Guide of Euro Test Solutions Ltd(2009).
30. Liang et al" A new measure of uncertainty based on knowledge granulation for rough sets", Information Sciences, Elsevier, 179 458–470(2009).
31. Dahlberg G., " Materials Testing Machines investigation of error sources and determination of measurement uncertainty", EUROLAB International Workshop: Investigation and Verification of Materials Testing Machines, pp.21-32(2010).
32. Clark J.P, "Evaluation of Methods for Estimating the Uncertainty of Electronic Balance Measurements", Evaluation of Methods for Estimating the Uncertainty of Electronic Balance Measurements Page 2 of 20.(2010).
33. Alkhatib and Kutterer,"Towards an advanced estimation of Measurement Uncertainty using Monte-Carlo Methods-case study kinematic TLS Observation Process", FIG Working Week 2011 Bridging the Gap between Cultures Marrakech, Morocco, 18-22 May 2011(2011).
34. Gajghate,"Uncertainty estimation in analysis of particulate-bound mercury in different size fractions of PM10 in ambient air", Accred Qual Assur 16:459–465 DOI 10.1007/s00769-011-0785-y(2011).
35. Ledda, "Measurement uncertainty for the determination of the inhibitory effect on Vibrio fischeri: A practical approach", Journal of Environmental Chemistry and Ecotoxicology Vol. 3(5), pp. 139-141, May 2011.
36. Ramnath , "Determination of pressure balance distortion coefficient and zero-pressure effective area uncertainties", International Journal of Metrology and Quality Engineering / Volume 2 / Issue 02 / January 2011, pp 101-119(2011).
37. Laghi et al, " Uncertainty analysis of thermal conductivity measurements in materials for energy-efficient buildings", International Journal of Metrology and Quality Engineering / Volume 2 / Issue 02 / January 2011 , pp 141-151(2011).
38. Megahed and Abdelaziz , "Uncertainty evaluation in the calibration of Pt/Pd thermocouples up to copper freezing point at NIS-Egypt", International Journal of Metrology and Quality Engineering / Volume 2 / Issue 01 / January 2011, pp 13-17(2011).
39. Gupta and Kumar, "Propagation of Uncertainty in Establishing the Viscosity Scale", Mapan –Journal of metrology and quality engineering, Volume, 83-86(2012).
40. Kosarevsky and Latypov, "Practical Procedure for Position Tolerance Uncertainty Determination via Monte-Carlo Error Propagation", Measurement Science Review, Volume 12, No. 1, 2012.PP.01-07(2012).
41. Mandavgade et al," Use of statistical quality control for estimating machine interference" in International Journal of Measurement Technologies and Instrumentation Engineering, ISSN:2156-1737,Vol.2,Issue(1),PP.17-34,January–March,2012,DOI: 10.4018/ijmtie.2012010102(2012).
42. BIPM/IECIIFCC/ISO/OIML/IUPAC, ISBN 92 67 101889, 1993-95- Guide to the expression of uncertainty in measurement.
43. JCGM 100:2008 GUM 1995 with minor corrections Evaluation of measurement data Guide to the expression of uncertainty in measurement.
44. Euro lab Technical report 1/2002 June 2002 on measurement Uncertainty in testing, Euro lab Germany.
45. Mandavgade et al, "Determination of uncertainty in gross calorific value of coal using bomb calorimeter," International journal of measurement technologies and instrumentation engineering, ISSN: 2156-1737,(4),45-52,October-December (2011).
46. Mandavgade et al ,"Measurement uncertainty evaluation of automatic Tan Delta and resistivity test set for transformer oil" published in International Journal of Metrology and Quality Engineering (IJMQE) ISSN: 2107-6839 EISSN: 2107-6847, Cambridge University journal volume 3, issue 1, 39–45 DOI:10.1051/ijmqe/2012004. (2012)
47. Mandavgade et al, " Mathematical modeling of effects of various factors on uncertainty of measurement in material testing", proceedings of International conference on mechanical engineering and technology ICMET 2011 November 24-25, 2011, London, DOI:http://dx.doi.org/10.1115/1.859896.paper43 in ASME digital library(2011).
48. Awachat and Mandavgade, "Comparative Analysis of Measurement Uncertainty Associated With Brinell Hardness Test and Rockwell Hardness Test" in 5th International conference ICAME-2011, at SVNIT, Surat, 06-08 June, (2011).
49. Rotmans Jan Et Al,"Uncertainty Management in Integrated Assessment Modeling: Towards A Pluralistic Approach", Environmental Monitoring and Assessment 69: 101–130, 2001.
50. Mandavgade N.K.,Jaju S.B.,Lakhe R.R.,"Identifying uncertainty sources in measurements- A methodology", Journal of measurement science and instrumentation Sum No. 12,Vol 3 No 4 Dec PP 307-312(2012).
51. Splett J.D et al, "Computing uncertainty for charpy impact testing machine test results",National Institute od Standards and Technology Special Publication 960-18,34 pages (October 2008).