Towards the Selection of the Best Machine Learning Techniques and Methods for Urinalysis

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ABSTRACT
Urinalysis is a significant technique used for determining and inspecting the urinary system. Urine has numerous chemical materials secreted; these materials can be used to diagnose diseases and conditions such as urinary tract infection, diabetes, kidney diseases, and pregnancy, at the earliest. Accessing medical care and health screenings are quite essential, but it has become extremely difficult since screening techniques are either very expensive or convoluted for people of low-income communities. Despite the fact, that numerous urinalysis methods and techniques have been brought forth by researchers over the years, no research has been conducted to scrutinize and review state-of-the-art developments in the stated area. Hence, this research aims to conduct a Systematic Literature Review of urinalysis methods proposed and assessed from 2007 to 2019 and recognizes 33 studies. This leads to the identification of 10 methods, 8 technologies, 12 challenges, and 10 diseases. An insight analysis of the identified methods and models reveals that Genetic Based Fuzzy Classifying Method and Automatic Urinary Particle Recognition Method are the most optimum options due to the fact that their computational time is minimum as well as they do not require any supportive hardware. Moreover, the analysis of technologies reveals that Mobile App (Augmented Reality) is the best option among the identified technologies. It has also been discovered that machine/deep learning classification techniques have been used to classify the sample and provide reliable and accurate results within time. Nevertheless, a complete analysis of methods and technologies has been presented. The findings of this article are extremely useful for practitioners as well as academics of the area.

CCS Concepts
• **Computing methodologies→Machine learning approaches**

Keywords
Urinalysis; Urinalysis Strips, Urinalysis Methods, Urinalysis Technologies, Machine learning Application in Urinalysis, Deep Learning

ICMLC 2020, February 15–17, 2020, Shenzhen, China

ACM ISBN 978-1-4503-7642-6/20/02…$15.00
DOI: https://doi.org/10.1145/3383972.3384031

1. INTRODUCTION
For quite some time, urinalysis has been one of the most commonly used tests for diagnosing disease and conditions. The process of urinalysis is the same in most laboratories i.e. using chemical test strips, microscopy of urine sediments and urine flow cytometry [1]. The main use of urinalysis is determining the incidence of chemical configuration in urine, which can be conducted by making use of urine dipsticks reagents. Usually, a stick is dipped in the collected sample of urine and then the reactive color of each reagent is visually compared with the dipstick color chart [2]. Numerous functions of the body can be illustrated by performing the urinalysis. Urinalysis is a significant procedure used worldwide for diagnosing many diseases such as kidney diseases, urinary tract infection, diabetes, bladder inflammation, syphilis, infectious disease, diabetes insipidus, and glucosuria, but is time-consuming and costly; other methods are fast but moderately reliable [3]. Despite the fact that numerous methods and techniques have been presented in the stated domain, no research article is available which analyze and summarizes the newest urinalysis developments. Hence, in this article, a Systematic Literature Review (SLR) has been performed in order to recognize 33 studies published in the period of 2007-2019. This study also presents and answers the following research questions.

RQ1: What are the leading machine learning techniques currently used for urinalysis?

RQ2: What leading machine learning technologies have been used for urinalysis?

RQ3: What are the main challenges faced in urinalysis?

RQ4: Which diseases/conditions can be diagnosed by making use of urinalysis?

2. RESEARCH METHODOLOGY
The guidelines of SLR have been used to conduct this research. The following subsections are used to describe the details of the methodology of this research.

2.1 Review of Protocol Development
According to SLR guidelines, the review protocol is set after defining the research questions. The review protocol is used to define the background of urinalysis, research questions, the criteria for selecting and rejecting researches, the method used during the search process, and extracting and synthesizing data.

2.2 Inclusion and Exclusion Criteria

2.2.1 Subject relevance

Subject relevance is the first and foremost criterion used for selecting relevant research papers that are the selected papers ought to be related to urinalysis. Latest publications: only those papers which have been published during the timespan 2007 – 2019 are considered in order to attain recent researches. Reliable Databases: it has been made sure that only quality research papers are considered, for this purpose papers that are published by reliable databases are considered. These databases are Taylor & Francis, IEEE, ELSEVIER, SPRINGER, and ACM. Effective Methods/Technologies and solutions: it has also been set as a criterion that some sort of technique is proposed and evaluated in the selected papers, and the proposed technique is relevant to urinalysis.

2.2.2 Search process

Search Process Taking the stated criteria into consideration, the databases have been searched to shortlist relevant article, using the predefined keywords. Table 1, Figure 1 and Figure 2 have been used to illustrate the search process.

2.2.3 Data extraction and synthesis

The stated procedure has been illustrated in the following table i.e. Table 2, where the elements of data extraction have been categorized in different groups in order to organize the process of data extraction and synthesis.

2.2.4 Quality assessment

The predefined criteria have been very assistive when it comes to performing analysis of the research articles and the methodology proposed by it or its findings. The criteria have also been of great use while understanding the influence of the techniques on urinalysis.

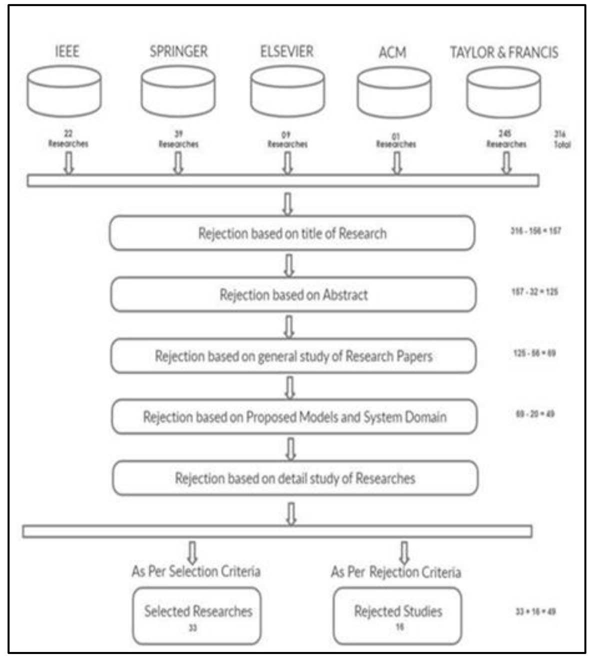

Figure 1: Search Process and Selection of Studies

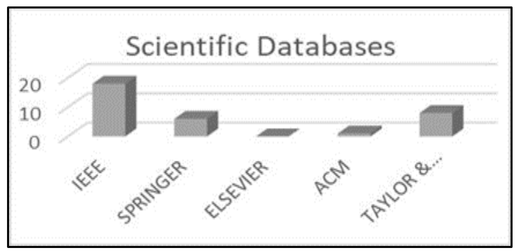

Figure 2: Paper Selected from Database

Table 1: Search Results

Search Term	No. of Search Results				
	IEEE	***SPRINGER***	***ELSEVIER***	***ACM***	***Taylor & Francis***
"Urinalysis Strips "	21	05	00	00	205
"Machine Learning AND Urinalysis Strips"	01	01	09	01	08
"Machine Learning Application AND Urinalysis"	00	17	00	00	25
“CNN And Urinalysis”	00	11	00	00	07
“CNN AND Urinalysis Strips”	00	05	00	00	00

Table 2: Elements of Data Extraction

Sr. #	**Description**	**Details**
1.	Bibliography	Author names, publication year, etc.
	Extraction of data	
2.	Overview	The fundamental aim of the selected study is to identify what models have been proposed during the period 2007 to 2019 For urinalysis. What kind of challenges have they faced, and the tools used or developed during the stated timespan?

3.	Results	Results attained by the selected article?
4.	Data collection	Whether the method used is Qualitative or Quantitative?
6.	Validation	Researched and verified via various sources described in the paper.
Synthesis of data		
7. 8. 9. 10.	Methods Technologies Challenges Disease	Methods proposed for urinalysis. Technologies used for urinalysis Challenges related to urinalysis Disease/ Conditions diagnosed by Urinalysis

3. RESULTS

This section summarizes the results that are obtained through the detailed analysis of selected studies. In this article, 33studies have been identified in the area of urinalysis. 10 urinalysis methods have been identified as given in Table 3.

Table 3: Urinalysis Methods

Methods	Papers
Adaptive Sampling Ensembles learning Method (ASELM)	[1]
Intelligent Dipstick Urinalysis Method	[2]
Color Strip Test Method	[4]
Inkjet Printing Dipstick Method	[5]
Multiple Photometry Method	[6]
Stamping Method	[7]
Hand Stamped Urinalysis Method	[8]
Flow Cytometry Method	[3][9]
Genetic Based Fuzzy Classifying Method	[10]
Automatic Urinary Particle Recognition Methods	[11][12][13]

Adaptive Sampling Ensembles Learning Method [1] is a hybrid approach of ensemble learning which combines CSM a method of adaptive sampling. By using this method, the dataset quality increases, and evaluation is done using several measurements. The goal of this work is to study the potential of AdaBoost, Random Forest and Bagging and to building a combined method to decrease the error of urinalysis. Intelligent Dipstick Urinalysis based on a framework uses a smartphone camera to capture the colors. It also covers the other color-related properties such as quantification, color correction, color management system and color matching [2]. Color Strip Test Method [4] can produce the results of several urine strips at the same time by analyzing the color of the strip. The results are precise as an expert would decide. That is why this method can be used as an alternative to automated devices and expert. Hand Stamped Urinalysis Method presents colorimetric detection assays for metabolism. For example, ketone and glucose can be cheaply and competently stamped on filter paper and it can be compared with similar specificity commercial product [5]. Inkjet Dipstick can be used for a variety of screening tests including diabetes and urinary tract infections [6].

In Multiple Photometry Method, several colorimetry units are adopted in order to measure the urinalysis of the multi-pad dipstick. Many photometry methods as a replacement for moving mechanisms has the benefit of a simple, reliable and economic system [7]. Stamping Method has a wide scope in the field of medical care for humanitarian engineering level. It consists of manual foam stamp and filter paper and selected due to its high imprint consistency, low cost, and ease of use [8]. Flow Cytometry has the system and comparison are made with the Color pads reference to get the concluding classification. Highest diagnostic accuracy and is superior to other methods in urinalysis in febrile patients in the emergency department when using urine culture as the gold standard [3] [9]. Genetic Based Fuzzy Classifying Method is based on classification. It also identifies and monitors infection in the urinary tract and kidney diseases by generating fuzzy rules. In today’s world, this learning of Fuzzy genetic is globally carried out in major medical tests just because it has proven its worth [10]. The method of Automatic Urinary Particle Recognition works by detecting the objects. This approach uses faster R-CNN, Convolutional Neural Network-based object detectors and single shot multibox (SSD. These methods can learn tasks-oriented features, and these are segmentation free [11][12][13].

Table 4: Urinalysis Technologies

Technologies	Papers
Mobile App (Augmented Reality)	[14]
Smart Phone-Based Colorimeters	[15]
Mobile urinalysis for Maternal Screening (MUMS)	[16]
Electronic Medical Database (ECMED)	[17]
Pocket-Sized Colorimetric Urine Reader	[18]
Strip Test App (Biochemical Test)	[19]
Point of Care testing (POCT)	[20][21] [22][23]
Smart bedit	[24]

Table 4 has been used to identify 9 technologies in the field of urinalysis. (Augmented reality) Mobile App can trace the orientation and position of a printed test automatically. The printed report automatically enables color calibration because it contains a pattern of reference color. This method does not need any hardware, it is very scalable, and any colorimetric test geometry can adopt it easily [14].

Smart Phone-Based Colorimeters innovations work with a mobile app which is attached with a sample holder of cheap 3D printer. It enables the device to manage conditions like lightning which increases the sensitivity [15]. Another mobile app is Mobile Urinalysis for Maternal Screening, it contains a lightbox. The lightbox enables urinalysis test implementation of pregnant ladies. This app is low-cost. The result of these tests flags warning signs if someone has health concerns at an early stage of pregnancy [16]. The medical record of patients is kept in computer-based database (ECMED) and it can be accessed through the internet or any other network. The important information about the patient and the medical tests results such as reports of urinalysis are saved in this database [17].

Pocket-Sized Colorimetric Urine Reader: it contains a module which is based on the novelty that detects colorimetric. It involves 3 chromatic parts: silicon photodiodes (SPD), poly optical splitter (POS) and light-emitting diodes (LED) [18]. Strip Test App (Biochemical Test): it uses a smartphone camera to get the strip's color pads pictures [19]. Later examines those pictures within the Point of Care testing (POCT): this Technology arranges the reference array with a new way for the urinalysis test. Doughnut chart represents the groups of reference color. The evaluation of the urine test can be done manually (with a naked eye) without any additional information by referring to the strip. For the diagnostic results delivery, another way is the proposed algorithm which is a smartphone app. The proposed approach of colorimetric detection estimates the images which were captured from the strip. It also estimates several tests for urine [20][21][22][23]. Smart Bedit: toilet stool which contains a sensor for urine measurement. It is linked to the server of the home videophone. This is an intelligent device for digital home users and evaluates tests of urinalysis [24].

Table 5: Urinalysis Challenges

Challenges	**Papers**
Noisy and Imbalance data	[1]
Small data set	[1]
Low image quality	[4][19][25]
Test Complexity	[14]
Color Inconsistency	[2]
Light Intensity	[2] [15] [19][21][22] [26]
User Intervention	[17][19][20]
Prone to human error	[20]
Difficult to interpret results with the naked eye	[21]
Need microscopic examination	[21]
Time Consuming	[3][5][26]
Labor intensive	[26]

12 Urinalysis challenges have been identified as given in Table 5. Issues faced by urinalysis i.e. Noisy and Imbalanced data sample of urine can increase the difficulties in identifying and classifying of diseases related to urine [1]. Small data set also affect accuracy. So, it is required to increase the number of urine sample for better accuracy and classification [1]. The image quality of the system is low because the system uses a webcam for capturing urine samples [4][19][25]. Test complexity is also increased because of many new varieties of colorimetric which can be used for testing multiple parameters simultaneously [14]. It also creates a challenge for interpreting the results with the naked eye due to color inconsistency and light inconsistency [2][15] [19][21][22] [26]. User intervention is required which is more prone to human error [17][19][20]. Urinalysis process is labor-intensive, time-consuming and required microscopic examination because sometimes it becomes difficult to interpret result with the naked eye [3][21][26].

In this article, 10 diseases that can be diagnosed at early stages with the help of urinalysis have been identified, as given in Table 6.

Table 6: Diseases

Disease	**Papers**
Kidney Disease	[4] [8] [10][11] [18] [24][27][28] [29]
Urinary tract infection	[4][5][6][7][8][10][11][13][18][26] [28] [30] [31] [32]
Diabetes	[2][4][6][8][15][19][22][29][32]
Pregnancy	[14][15][16][19][30]
Syphilis	[8]
Diabetes insipidus	[29]
Tumor	[29]
Bladder Inflammation	[29]
Infectious disease	[29]
Glucosuria	[12][19][33]

4. ANALYSIS OF URINALYSIS METHODS /TECHNOLOGIES

4.1 Analysis Criteria for Urinalysis Models

Has the classification been done using machine/deep learning algorithms? b) Does it take more time to perform urinalysis? c) Does it cost more? d) Does it require Labor to carry out the process? e) Does it require a microscopic examination to validate the results? f) Does it require any hardware such as i.e. urine analyzers, color detectors? g) Does it cover all of urines contents such as Bilirubin, PH level, Glucose Level, Leukocytes, Red Blood Cells, White Blood Cells, Nitrates, Proteins and ketones?

4.2 Evaluation Outcome of Methods

In the given analysis of 10 methods/models as shown in Table 7, Genetic Based Fuzzy Classifying Method and Automatic Urinary Particle Recognition Method are the best options because in contrast to other it allows you to perform urinalysis using machine learning classification algorithms within minimum time [11][12][13]. Besides this, it does not require any supportive hardware and covers all aspect of urinalysis with minimum cost [10].

4.3 Analysis of Urinalysis Technologies

Analysis Criteria: Each suggested technology is evaluated based on; a) Machine/Deep learning-based classification b) Portability: How easily It can be carried or moved from one place to another c) Cost: How much will be the procedural cost d) Online Accessibility: Does it require online access to store or retrieve patient records in the database? e) User-Friendly GUI: How easily it can be used to perform urinalysis and how easily it can be learned or understand f) Hardware: Does it require any additional hardware?

4.4 Evaluation Outcome of Technologies

The analysis of Technologies is given in Table 8. 8 Technologies have been identified and analyzed that have been proposed in different studies. Cording to analysis, it has been found that Mobile App (Augmented Reality) has been considered the best option among all identified technologies [14]. Machine/deep learning classification techniques have been used to classify the sample and provide reliable and accurate results within time.

Table 7: Analysis of Urinalysis Methods

Methods	Criteria						
	Classification	***Time Consuming***	***Cost***	***Labor-Required***	***Microscopic Examination***	***Hardware Required***	***Cover All Contents of Urine***
Adaptive Sampling Ensembles learning Method (ASELM)	Yes	Yes	Average	Yes	Yes	Yes	Yes
Color Strip Test Method	No	Yes	High	Yes	Yes	Yes	Yes
Hand Stamped Urinalysis Method	No	Yes	Average	Yes	No	Yes	No
Intelligent Dipstick Urinalysis Method	No	Yes	Average	No	Yes	Yes	Yes
Inkjet Printing Dipstick Method	No	Yes	Low	No	No	Yes	No
Multiple Photometry Method	No	Yes	Average	Yes	No	Yes	Yes
Stamping Method	No	Yes	Low	Yes	Yes	No	No
Flow Cytometry Method	No	Yes	High	Yes	Yes	Yes	NO
Genetic Based Fuzzy Classifying Method	Yes	No	Average	No	No	No	Yes
Automatic Urinary Particle Recognition Method	Yes	No	Average	No	No	No	Yes

Table 8: Analysis of Urinalysis Technologies

Technologies	Criteria						
	Classification	***Portable***	***Cost***	***Online Accessibility***	***User-Friendly GUI***	***Hardware Required***	***Cover All Contents of Urine***
Mobile App (Augmented Reality)	Yes	Yes	Low	No	Yes	No	Yes
Smart Phone-Based Colorimeters	No	Yes	Average	No	Yes	No	Yes
Mobile urinalysis for Maternal Screening (MUMS)	No	No	High	Yes	No	Yes	No
Electronic Medical Database (ECMED)	No	No	High	Yes	No	Yes	Yes
Pocket-Sized Colorimetric Urine Reader	No	Yes	High	Yes	No	Yes	Yes
Strip Test App (Biochemical Test)	No	Yes	Low	No	Yes	No	Yes
Point of Care testing (POCT)	No	Yes	Average	No	Yes	No	Yes
Smart bedit	No	No	High	No	Yes	Yes	Yes

5. CONCLUSION AND FUTURE WORK

In this article, a Systematic Literature Review has been performed to identify the latest development in the area of urinalysis. Particularly, 33 research studies which have been published during 2007-2019 related to the specified domain have been identified and analyzed. This leads to the identification of 10 methods, 8 Technologies, 12 challenges, and 10 diseases. Furthermore, an insight analysis, of the identified methods and models, reveals that Genetic Based Fuzzy Classifying Method and Automatic Urinary Particle Recognition Method are the most optimum options due to the fact that their computational time is minimum as well as they do not require any supportive hardware. Moreover, the analysis of technologies reveals that Mobile App (Augmented Reality) is the best option among the identified technologies.

When health is at stake, diseases need to be diagnosed timely in order to prevent them from threatening vital human life. That is the reason why these results can be improved, and hence further research is intended to be carried out in order to deliver better solutions to the challenges confronted by urinalysis. Besides this, a detailed analysis of known challenges will be carried out in future researches as well.

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