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IoT-Based Smart Toilet System to Detect Bacteria and Amount of Uric Acid in Urine

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ABSTRACT

IoT in healthcare refers to integrating connected devices and sensors to collect and transmit data, enabling remote monitoring, real-time analytics, and improved patient care. The uric acid test in urine is a diagnostic method that measures the uric acid level in a person's urine and can help diagnose and manage diseases such as gout, kidney stones, and some metabolic disorders. Urinary Tract Infection (UTI) test or urinary tract infection test is a diagnostic method used to detect the presence of bacteria or other pathogens in a person's urine. It usually involves collecting a urine sample and analyzing it for the presence of bacteria, which can indicate a urinary tract infection. Early diagnosis of these diseases prevents more damage to the body, and it is vital to diagnose these diseases in people at risk. This research proposes a system utilizing UV-vis and fluorescence sensors integrated with the Internet of Things in a dedicated toilet. It aims to detect infectious diseases and kidney abnormalities in urine swiftly. Smart toilets can provide continuous preventative health monitoring at home for early disease detection while connecting to data servers (using the Internet of Things) to collect user's health status.

Keywords: Internet of Things, Smart toilet, Healthcare, Uric acid test, kidney diseases

1. Introduction

Urinary tract infections (UTIs), which are common among the general population, result in the visitation of 8.1 million people to hospitals in the United States of America every year [1], [2]. Also, it has been reported that a variety of diseases can be caused by abnormal processing of uric acid, which can be detected by assessing the level of uric acid in urine [3]. Uric acid is mainly produced by the liver through tissue metabolism. If there is a high level of uric acid in the blood, it has the potential to crystallize and deposit on the joints and kidneys]5[,]4[. During the early stages of disease formation, patients may not encounter any major problems, but later, they may face issues such as Dysuria, Polyuria, Haematuria joint pain and other symptoms. Irreversible damage to other organs may occur in the advanced stages of UTI or other diseases [6], [7].

Many urine tests in hospitals are reported as negative, resulting in wasted resources and additional pressure on lab employees. Early detection of urinary tract disease can prevent damage to other organs, and it's important to assess patients who are sensitive to avoid other problems continuously.

IoT-based systems have been developed and used more frequently because of technological advancements, particularly the widespread use of the Internet and mobile phones. Due to these features, the Internet of Things is used in various environments , such as smart homes, health, and transportation. In healthcare, IoT can have a significant impact on the healthcare system by giving opportunities to improve patient care, communication, decision support, and accuracy [8]. The lack of communication tools among professionals in healthcare further emphasizes the importance of functional interoperability to improve coordination. The healthcare system requires the monitoring of patients' vital signs, which include temperature, blood pressure, and heart rate. Even though doctors are constantly monitored in intensive care units and operating rooms, there are times when they are not promptly informed. Moreover, it is a challenge to share data remotely with specialists or family members. Despite the existence of technologies that can address these issues, they are typically too expensive for individuals in developing countries. A cost-effective solution to this problem could be achieved by adding a simple addition to current devices without these capabilities [9], [10], [11].

Several studies have been done on smart toilet, for example, Bae and Lee [12] on the analysis of disease and feces data using a toilet that studied the ability to separate infection and feces. The method of data collection in this model is by using IoT Sensors, and data collection is done on the Cloud. There is no Prediction Model in this system. In another study by Tuli et al]13[, who studied data analysis for heart diseases and its calculation on the cloud using the Internet of Things. Prediction Model has been used in this system. Another study by Syafaah et al]14[presented the design of a smart toilet using a camera as a color sensor and a color checking model with an RGB code that can calculate glucose using color. In another study, Bhatia et al]15[, who proposed a system that uses biosensors and IoT sensors to receive information through urine, receive this information using a color-coded mechanism. A prediction system analyzes this information. The system proposed by Bhatia et al can predict urinary detectable diseases. Huang et al [16] worked at smart toilet device that using multiplate sensors extract data like ECG, body wight and body fat of the users. Shinganwade et al [17] designed a public smart toilet system by using multiple sensors to detect cleanness of public bathrooms. Anisha et al. [18], by analysis of the previously extracted data (Temperature of Patient, Lumbar pain, Urine Pushing, Micturition pains, Burning of urethra, itch, swelling of urethra outlet, Inflammation of urinary bladder, Nephritis of renal pelvis origin) developed a ML model to predict the UTI in IoT-Fog Environment.

In this study, urinary diseases and how to identify them have been discussed. Additionally, we propose the design of a system capable of detecting the concentration and presence of uric acid and impurities in urine using two main sensors and one volume sensor. The system can determine if a person is ill by analyzing this data.

1.1 Principles of spectroscopy in molecular diagnosis

Urine is composed of uric acid and other substances]19[. The UV absorption spectra of common substances found in urine can be seen in Figure 1. The study reveals that uric acid and creatinine exhibit strong absorption characteristics even at low concentrations. It is notable that only one of the absorption peaks of uric acid takes place at a wavelength longer than 280 nm in the UV range. According to this observation, the absorption spectrum in the 290-300 nm range has little interference from other urine compounds when detecting uric acid. The study has identified a particular spectral feature at 290 nm in urine that is associated with the absorption peak of uric acid. By analyzing the absorbance at 290-300 nm, we can determine the concentration of uric acid in urine [20]. By detecting the decrease or increase of uric acid in the urine, it is possible to diagnose diseases such as gout, fatty liver, Parkinson's, nephrolithiasis, dehydration [21], [22].

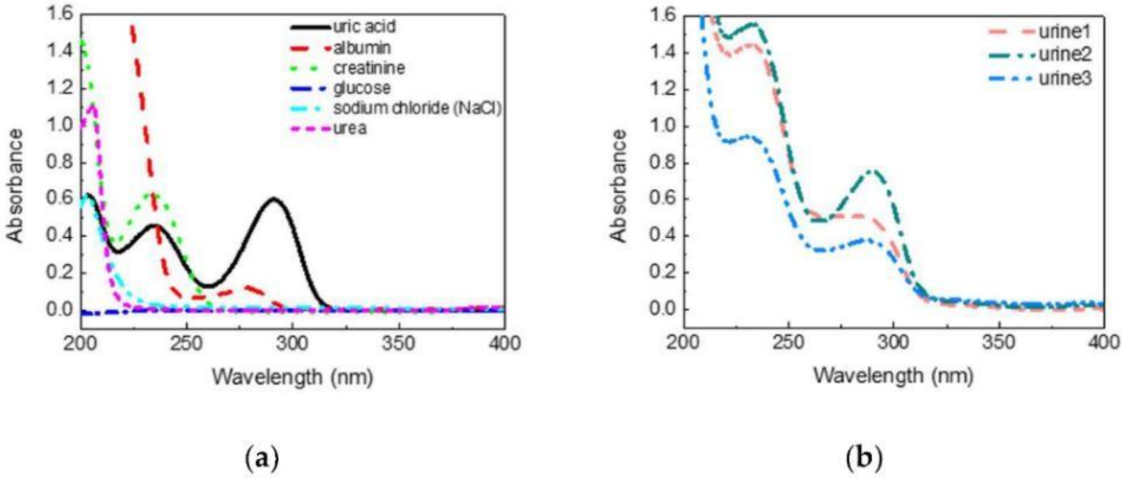

Figure 1 - Label-free estimation of uric acid in spot urine using a portable device based on UV spectroscopy (a) UV-vis spectroscopy data of each component of urea, (b) real sample UV-vis spectroscopy data from 3 different patient [23]

According to the results of the analysis and the UV production analysis, a prototype of the cargo in Figure 1b for the estimation of uric acid was created without the point label added in this study. In research, a total of 58 test samples were tested to compare the accuracy of the prototype carried by the biochemical analyzer. For prototyping reasons and to consider convenience in everyday life, complex samples were diluted six times and were not volumized at acid values less than 40 mg/dI. Therefore, only 24 are shown in the figure below. The standard deviation of the range of the given points is 0.75 mL g/dL. The coefficient of determination of the prototype carrying load without a label and biochemical analyzer was 0.8083, which indicates the possibility of analysis performed by a portable device on UV spectrophotometry for the detection of uric acid in diseases without enzymes. The selected LED wavelength was 290 nm instead of 300 nm due to the limitation of LED availability. This device is not a substitute for biochemical analyzers, but to create the opportunity and possibility to respond to the need for real-time monitoring of uric acid in clinical use and public health.

1.2 Fluorescent sensors are used to diagnose urinary diseases

The functioning of fluorescence sensors that detect the presence of impurities in urine is explained below. an atom or molecule receives light and its electron becomes excited. After returning to the ground state, it releases a photon. The sensor is set to 290nm (the exciting band of bacteria) to measure the emission. If the number obtained as shown in the figure below is higher than 0.3×10^4, the person probably has UTI. As shown in Figure 2, the red dots displayed people with UTI [24].

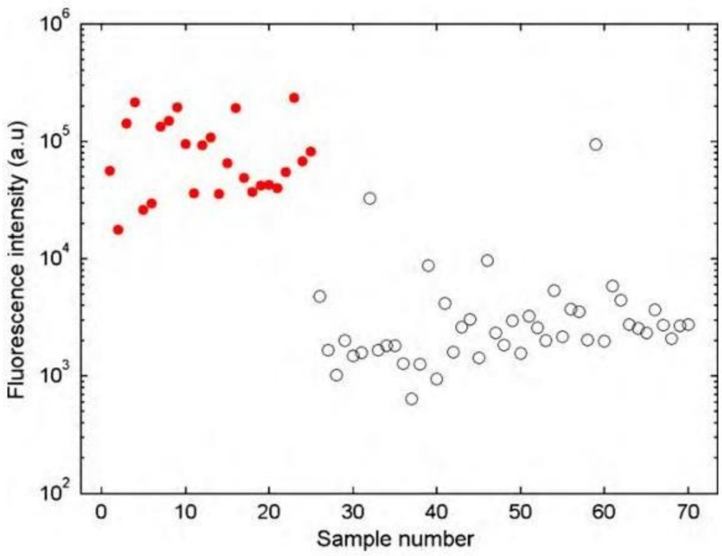

Figure 2 - Comparison of maximum fluorescence intensity (emission intensity) for 45 undiluted normal human urine (◦) and 25 undiluted bacteriuria samples (●) at an excitation wavelength of 290 nm. $P = 2 \times 10^{-12}$, by Kolmogorov-Smirnov (KS) test.[24]

Research Gaps: By studying and reviewing the research conducted in the field of smart toilet and the use of IoT technology in human health, the following can be considered as Research Gaps in the field of combining the Internet of Things and smart toilet.

1- A few studies have been done in the field of combining smart toilet and Internet of Things and use in homes.

2- A few studies have been done on the combination of smart toilet and human health.

3- Most of the studies are limited to the cleanliness of the environment or physical health. Also a few studies have been done in the fields of IoT combined with urine and smart toilet.

2. Proposed System

Smart homes with smart devices must be able to collect data with the sensors, camera, and any other device process, and create a suitable response to the data without any direct user input or environmental input for them to be widely used by people. Our proposed system consists of parts local and server side, in Table 1 sensors, hardware, and software systems required by our proposed model are listed and categorized in these two parts. The following section explains these two parts.

Table 1- Equipment and requirements

No.	Local	Server Side
1	Sensor UV-Vis	Database and Object–relational mapping (ORM) from Prisma Sqlite
2	Sensor Florescence	Next.Js framework JavaScript programming language
3	Sensor Fingerprint	JavaScript programming language of the React.Js framework
4	Sensor Capacitance level	Vercel server
5	Raspberry Pi hardware board	Push Notification from Firebase
6	Mobile Application	-

The presented system has two parts: Local (sensors, and computers), Server Side (database and software). Each parts is created to accomplish tasks required to attain the overall objective of defining the interface. To design this system, UV and Fluorescence sensors are used to detect the presence of bacteria and the amount of uric acid in urine, and Capacitance level sensors are used to measure the volume of urine and fingerprint sensors are used to connect user data to their account. After each usage, the output data is placed in relation (1) and provides an indication of the quantity of uric acid. Figure 3 shows the proposed system inside the urine section of our smart toilet.

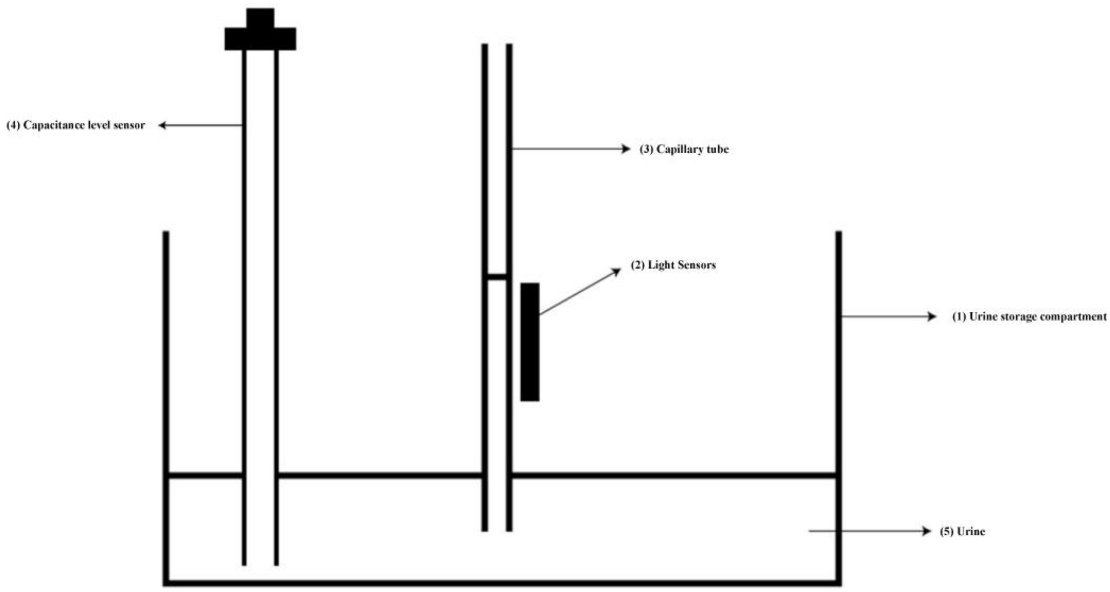

Figure 3- Schematic design of the diagnostic system

1- **Urine storage compartment:** It is a sterile container for temporary storage of urine with dimensions of 3.5 cm in radius and 20 cm in height.

2- **Light Sensors**: In this section, the two sensors used in proposed plan, which are fluorescence and UV.

3- **Capillary tube**: The reason for using a capillary tube in this test is its capillarity property that exists in liquids [25] The diameter of the capillary tube influences the result of our experiment.

4- **Capacitance level sensors**: to calculate urine volume in 24h.

In the proposed design, a fingerprint sensor is installed on the toilet flush button, enabling users to associate their test results with their fingerprint and save them in the system.

In the gateway section, information is received from sensors and sent to the server for storage and calculation through the Internet. Data is transferred between the device and the server using Rest API.

Second layer: Internet network and servers

The server will calculate and store the data, and the user will be alerted if necessary.

Third layer: automation software and mobile application

The analysis of the information will be done on the server, and the result of this information will be displayed to the user through a push notification if the test is positive.

2.1 Data analysis method

2.1.1 UV-vis sensor range

According to studies [21], if the amount of uric acid excreted in a day is between 1.48 mmol and 4.43 mmol, the person is not sick, and if it is higher or lower than this value, the person is sick.

2.1.2 Fluorescence sensor range

To check the amount of emission in this sensor, we set the sensor settings to 290nm. If the number obtained below is higher than (0.3×10^4), the person is probably sick.

Equation (1) is used for the final calculations of the UV-vis sensor data and obtaining the amount of uric acid [26].

= — (1)

In equation (1) C represent the amount of excreted uric acid is in millimoles, A is the number obtained from the UV-vis sensor, L denote the length of the light path, which is equal to 0.3 cm Ɛ is the optical absorption constant of uric acid at 292 nm. The unit of this parameter is $mM^{-1}cm^{-1}$, and V is the volume of urine excreted in 24 hours in units of liters, which is obtained from Capacitance level sensors.

Paul A. Monach's studies suggest that repeating clinical trials is a common way to decrease the error rate of the systems used. For this purpose, in this system, we have considered three tests for the fluorescence sensor and two tests for the UV-vis to reduce the system error]27[.

2.2 System workflow

At the beginning of using this system, the user is asked questions, these questions are as follows:

Name, Last Name, Gender, and age: To register the user in the smart toilet application.

The system always checks the fluorescence test first and only checks the UV sensor information if the result of the fluorescence test is negative. Fluorescence test requires 3 positive results to be reported as positive. There is no specific time limit for this test and it can be performed at various intervals. If the fluorescence test fails every time, the UV test data is examined. According to Figure 4, if the UV test is also negative, the person is healthy, but when the UV test is positive, the system asks the user, using its application, if he has used the toilet outside the house in the last 24 hours. is it or not If this answer is positive, the result of this test is negative, and if the answer is negative, the system calculates the user's data with the previous day, and if the previous day was also positive, it sends a notification to the user to go visits a doctor. The system workflow shown in the Figure 4.

And considering that our system examines the information in real time and the fact that urinary infectious diseases can be diagnosed only after few hours of infection [21], the prediction system does not need a feeling for this.

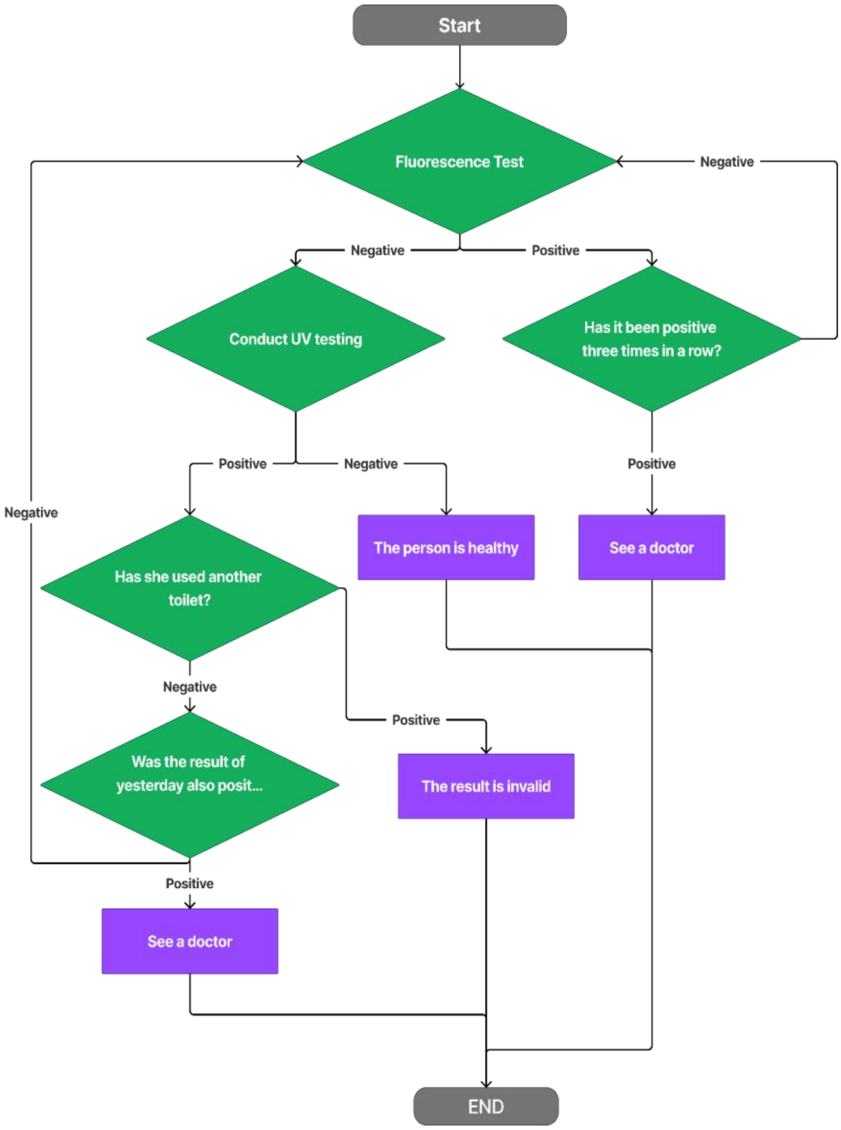

Figure 4 - System workflow

2.2 Mobile Application

In the mobile application designed for this smart toilet, as explained in the workflow, gender and user information is received at the time of registration, and this application can be used to manage sending notifications to the user. Urine test results from the sensor is sent to the server through the gateway and internet, and using HTTPS and Rest Api protocols, these results sent from the server to the mobile phone. The User Interface of our mobile application show in Figure 5.

Figure 5 – User Interface of the mobile application

Alcohol can also be used in the proposed toilet environment, along with UV lamps. The toilet siphon is used to completely sterilize and clean the test environment with water, making it ready for reuse.

In tables 2 and 3, the algorithm and workflow of the system has been tested using sample data, and the analysis of the system has been confirmed manually by expert urologists.

Table 2 - Analysis of data from 10 patients collected by the laboratory with the UV-vis sensor – red color in the table shows us the user is sick and the green one shows that the user is healthy

patient	1 absorbance	volume	2absorbance	volume	3 absorbance	volume	4absorbance	volume	result 1	result 2	result3	result4	day 1
patient1	1.57	308	3.94	416	3.31	237	3.32	317	127.9259	433.6085	207.5317	278.4233	1047.489
patient2	3.24	398	0.82	330	3.87	398	2.32	207	341.1429	71.5873	407.4762	127.0476	947.254
patient3	2.17	287	0.7	300	0.74	445	1.73	334	164.7593	55.55556	87.1164	152.8624	460.2937
patient4	2.27	330	2.05	315	3.12	296	2.89	264	198.1746	170.8333	244.3175	201.8413	815.1667
patient5	2.84	289	1.12	214	1.32	352	1.27	411	217.1323	63.40741	122.9206	138.0873	541.5476
patient6	1.43	388	3.81	374	3.96	229	1.55	479	146.7831	376.9683	239.9048	196.4153	960.0714
patient7	3.81	474	1.8	452	1.32	373	1.22	403	477.7619	215.2381	130.254	130.0688	953.3228
patient8	3.3	493	1.95	374	1.79	401	3.75	382	430.3968	192.9365	189.8915	378.9683	1192.193
patient9	1.81	262	1.09	421	1.32	441	3.2	214	125.455	121.3995	154	181.164	582.0185
patient10	3.86	354	2.03	203	3.63	315	2.82	253	361.4921	109.0185	302.5	188.746	961.7566

patient	1 absorbance	volume	2absorbance	volume	3 absorbance	volume	4absorbance	volume	result 1	result 2	result3	result4	day 2
patient1	1.08	397	1.88	448	0.56	347	2.41	308	113.4286	222.8148	51.40741	196.3704	584.0212
patient2	0.8	304	1.77	315	1.17	494	1.64	291	64.33862	147.5	152.9048	126.254	490.9974
patient3	1.92	447	0.75	447	1.79	382	2.86	378	227.0476	88.69048	180.8942	286	782.6323
patient4	2.4	239	1.84	302	1.21	417	2.6	371	151.746	147.0053	133.4841	255.1852	687.4206
patient5	0.49	374	3.8	500	1.46	201	1.43	240	48.48148	502.6455	77.63492	90.79365	719.5556
patient6	1.9	377	1.5	479	3.19	383	3.87	325	189.4974	190.0794	323.2196	332.7381	1035.534
patient7	1.61	354	1.97	308	3.12	342	1.04	206	150.7778	160.5185	282.2857	56.67725	650.2593
patient8	2.79	382	3.49	275	2.12	490	3.71	362	281.9524	253.9021	274.8148	355.2963	1165.966
patient9	1.74	376	3.48	204	3.16	461	0.84	370	173.0794	187.8095	385.3862	82.22222	828.4974
patient10	2.1	215	3.19	262	2.96	288	2.73	293	119.4444	221.1058	225.5238	211.6111	777.6852

Table 3 - Analysis of data from 10 patients collected by a laboratory with a fluorescence sensor - red color in the table shows us the user is sick, and the green one shows that the user is healthy

patient	1st attempt	2nd attempt	3rd attempt
patient1	6428	2506	3744
patient2	403274	233746	257254
patient3	7378	651249	251542
patient4	7451	9563	846471
patient5	2250	916188	7760
patient6	5053	6104	9003
patient7	404688	7926	9524
patient8	539120	5959	600577
patient9	1329	2205	8261
patient10	984212	216028	564243

3. Conclusion

This research suggests that combining these two sensors and connecting them to an IOT system is possible and has many benefits in the field of health and monitoring the health of humans, especially high-risk people automatically. Early detection of abnormalities and diseases without symptoms can safeguard against irreparable injuries. In the early stages, this system can detect infectious diseases and systemic abnormalities in the urinary tract and prevent further damage to the patient's body. Given that laboratories waste significant amounts of raw materials every year due to negative results, this system has the potential to save both raw materials and laboratory labor.

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