Docket #: S17-445

A Fully-Automated Smart Toilet Mount for Continuous Human Health Monitoring

Engineers at Stanford have invented a smart toilet platform that will autonomously monitor excreted waste from humans. We describe easily deployable hardware and software for the long-term analysis of a user's excreta through data collection and models of human health. The 'smart' toilet, which is self-contained and operates autonomously by leveraging pressure and motion sensors, analyses the user's urine using a standard-of-care colorimetric assay that traces red–green–blue values from images of urinalysis strips, calculates the flow rate and volume of urine using computer vision as a uroflowmeter, and classifies stool according to the Bristol stool form scale using deep learning, with performance that is comparable to the performance of trained medical personnel. Each user of the toilet is identified through their fingerprint and the distinctive features of their anoderm, and the data are securely stored and analysed in an encrypted cloud server. The toilet may find uses in the screening, diagnosis and longitudinal monitoring of specific patient populations.

Figure



Figure description- A perspective view of a toilet with a mountable device for continuously measuring baselines of human excreta. The toilet system includes (1) a 10-parameter test-strip-based urinalysis with a retractable cartridge; (2) computer-vision uroflowmetry with two high-speed cameras (the blue dotted lines represent the FOV from each camera); (3) stool classification by deep learning (the blue dotted lines represent the FOV of the defecation monitoring camera); (4) defecation time measurement detected by a pressure sensor below the toilet seat (the red arrow represents the force applied to the pressure sensor); (5) two-biometric identifications, an analprint scan (the green box represents the template-matching algorithm) and a fingerprint scanner on the flush lever; and (6) the ability to transfer all data by wireless communication to a cloud-based health portal system. Right: photographs of the actual system mounted on a toilet.

Image credit: Adapted from the publication in Nature Biomedical Engineering

Stage of Research:

- Prototype tested with 21 male/female subjects
- Continued work to improve prototype
- Conducted the user acceptance survey (300 survey respondents)

Applications

- **Human health continuous monitoring in homes, hospitals and clinics, military and workplace**

- Personalized testing based on patient health profile. Can test for diabetes, infections,
- Customized urinalysis
- Monitor patients undergoing surgery/chemotherapy/radiotherapy
- Screen for certain cancers, irritable bowel syndrome (IBS), and GI diseases (Crohn etc.)
- Monitor drug use, sexually transmitted diseases
- Potential targeted diseases



Disease/Symptom	Biomarker/Measurement	Current test
Urination		
Nocturia (congestive heart failure, sleep apnea)	Frequency, time of day	Urine diary
Oligo-/polyuria	Volume	Urine diary
Benign prostatic hypertrophy	Flow rate vs. duration of urination	Uroflowmetry
Urinary retention (medications, surgery)	Decreased or absent urination	Uroflowmetry
Skin morphology		
Morphological changes to the external genitalia	Non-infectious skin diseases (e.g. Lichen planus/sclerosis, M. Paget), infectious skin disease (e.g. genital warts, balanitis)	Image analysis
Urinalysis		
Dehydration	Urine volume, color, specific gravity	Strip, uroflowmetry
Diabetes	Frequency, glucosuria, proteinuria	Urine diary, strip*
Urinary Tract Infection	Frequency, WBC, Nitrites	Strip*
Pregnancy	β-hCG	Strip*
Ovulation	Progesterone, follicle stimulating hormone (FSH), luteinizing hormone (LH), estrogen	Strip*
Intrinsic renal disease (e.g. glomerulonephritis, nephrotic syndrome) Ψ	Proteinuria, hematuria, cellular casts	Strip*
Kidney Stones Ψ	Hematuria, pH, mineral levels (calcium, oxalate, citrate, uric acid, sodium, potassium), total volume	Strip*
Alcohol	Ethyl glucuronide (EtG), >500 ng/mL	Strip*
Liver dysfunction/ Biliary obstruction Ψ	Bilirubin	Strip*
Cushing Syndrome, Addison's disease Ψ	Cortisol	Lab test
Illicit Drugs	AMP/BAR/BUP/BZO/COC/mAMP/MDMA/MTD/OPI/OXY/PCP/TCA/THC	Strip*
Renal Cancer	Hematuria, urine cytology	Strip, Cytology
Bladder Cancer	Hematuria, urine cytology, tumor-related proteins or nucleic acids	Strip, Cytology
Multiple Myeloma Ψ	Proteinuria (Bence Jones protein)	Strip, Lab test
Sexually transmitted diseases	Chlamydia, Gonorrhea	NAATs
Prostate Cancer Ψ	Prostate cancer gene 3 & PSA RNA	NAATs
Urothelial cancer Ψ	Urine cytology	Cytology

Current Model

Disease/Symptom	Biomarker/Measurement	Current test
Defecation		
Irritable bowel syndrome (IBS)	Fluctuation in stool frequency, consistency	Stool diary, BSFS
Constipation	Seating time, BSFS, initial stool drop time	Stool diary, BSFS
Fecal incontinence	Presence of stool in the perianal area, fecal incontinence score	Stool diary, BSFS
Low anterior resection syndrome	Frequency, initial stool drop time, total toilet sitting time, straining, fecal incontinence score	Stool diary, BSFS
Skin morphology		
Morphological changes to the perineal area	(Traumatic) skin lesion, swelling	Image analysis
Stool analysis		
Disease monitoring		
Chemotoxicity (GI)	Constipation, diarrhea, stool frequency, BSFS	Clinical correlation with chemotherapy
Pseudomembranous colitis (antibiotic related)	BSFS, diarrhea, stool frequency	Colonoscopy, biopsy
Radiation induced proctitis	BSFS, diarrhea, stool frequency, bleeding	Clinical correlation with radiation therapy
Inflammatory bowel disease (Crohn, ulcerative colitis)	Calprotectin, anal bleeding, diarrhea, perianal skin lesion, symptom severity quantification	Colonoscopy, blood test, biopsy
Celiac Disease	BSFS (Diarrhea)	Small bowel biopsy
Malabsorption	72-hour stool collection, BSFS, color	Lactose hydrogen breath test, fecal fat analysis, fecal bile acid test
Early detection		
Extrahepatic bile duct obstruction	Pale stool color	Fecal bile analysis
Steatorrhea	Vitamin A, D, E, K deficiency Fatty stool	Blood test, fecal fat analysis
Salmonella, E.coli, Lysteria, C. diff, etc.	BSFS (diarrhea), bacteria/toxins	Stool culture
Colon cancer	gFOBT, mucoid stool, thin stool, stool DNA	Colonoscopy, CEA, biopsy

Future Model

Sensor & Image analysis
Biochemical analysis
Cell (product) analysis
* Commercially available
Ψ The Smart Toilet system might aid in monitoring or creating first awareness

- **Figure description**-Table. Current and potential disease/state screening that may benefit from the toilet system. The upper part of the table indicates capable disease/state screening with the current version of the toilet. The lower part of the table requires more advanced technology and higher-level system integration. NAAT: Nucleic Acid Amplification Test, BSFS: Bristol Stool Form Scale, AMP: Amphetamine, BAR: Barbiturate, BUP: Buprenorphine, BZO: Benzodiazepines, COC: Cocaine, mAMP: Methamphetamine, MDMA: Methylenedioxymethamphetamine, MTD: Methadone, OPI: Opiate, OXY: Oxycodon, PCP: Phencyclidine, PPX: Propoxyphene, TCA: Tricyclic antidepressants, THC: Tetrahydrocannabinol. *Image credit: Dr. Seung-min Park*

Advantages

- Fully automated with user ID, excretion detection, and analysis features
- Non-invasive
- Cost effective diagnostics
- Autonomous with continuous monitoring
- Employs deep convolutional neural networks (CNNs) for stool analysis
- Minimally interferes with normal human behavior in the toilet
- Personalized and multiuser, based on personal ID fingerprint, “anal print”, or weight sensors
- Customized assays based on patient profile
- Little to no maintenance required by the user

Publications

- S-m Park, D.D. Won, B.J. Lee…S.S. Gambhir A mountable toilet system for personalized health monitoring via the analysis of excreta *Nature Biomedical Engineering* 06 April 2020.

Patents

- Issued: 11,604,177 (USA)

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