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.
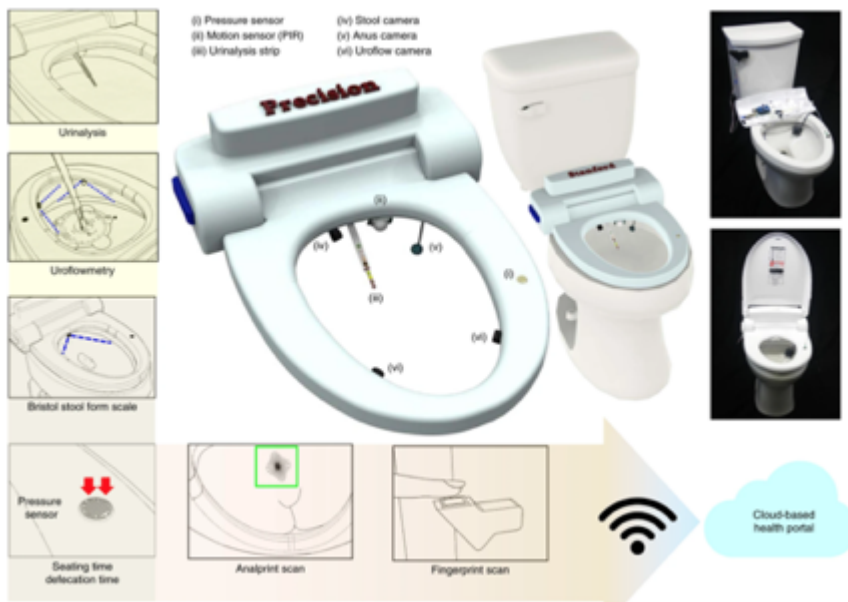
Figure

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		Disease/Symptom	Biomarker/Measurement	Current test
Urination				**Defecation**		
Nocturia (congestive heart failure, sleep apnea)	Frequency, time of day	Urine diary	Current Model	Irritable bowel syndrome (IBS)	Fluctuation in stool frequency, consistency	Stool diary, BSFS
Oligo-/polyuria	Volume	Urine diary		Constipation	Seating time, BSFS, initial stool drop time	Stool diary, BSFS
Benign prostatic hypertrophy	Flow rate vs. duration of urination	Uroflowmetry		Fecal incontinence	Presence of stool in the perianal area, fecal incontinence score	Stool diary, BSFS
Urinary retention (medications, surgery)	Decreased or absent urination	Uroflowmetry		Low anterior resection syndrome	Frequency, initial stool drop time, total toilet sitting time, straining, fecal incontinence score	Stool diary, BSFS
Skin morphology				**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		Morphological changes to the perineal area	(Traumatic) skin lesion, swelling	Image analysis
Urinalysis				**Stool analysis**		
				Disease monitoring		
Dehydration	Urine volume, color, specific gravity	Strip, uroflowmetry		Chemotoxicity (GI)	Constipation, diarrhea, stool frequency, BSFS	Clinical correlation with chemotherapy
Diabetes	Frequency, glucosuria, proteinuria	Urine diary, strip*		Pseudomembranous colitis (antibiotic related)	BSFS, diarrhea, stool frequency	Colonoscopy, biopsy
Urinary Tract Infection	Frequency, WBC, Nitrites	Strip*		Radiation induced proctitis	BSFS, diarrhea, stool frequency, bleeding	Clinical correlation with radiation therapy
Pregnancy	β-hCG	Strip*		Inflammatory bowel disease (Crohn, ulcerative colitis)	Calprotectin, anal bleeding, diarrhea, perianal skin lesion, symptom severity quantification	Colonoscopy, blood test, biopsy
Ovulation	Progesterone, follicle stimulating hormone (FSH), luteinizing hormone (LH), estrogen	Strip*		Celiac Disease	BSFS (Diarrhea)	Small bowel biopsy
Intrinsic renal disease (e.g. glomerulonephritis, nephrotic syndrome) Ψ	Proteinuria, hematuria, cellular casts	Strip*		Malabsorption	72-hour stool collection, BSFS, color	Lactose hydrogen breath test, fecal fat analysis, fecal bile acid test
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*		**Early detection**		
Liver dysfunction/ Biliary obstruction Ψ	Bilirubin	Strip*		Extrahepatic bile duct obstruction	Pale stool color	Fecal bile analysis
Cushing Syndrome, Addison's disease Ψ	Cortisol	Lab test		Steatorrhea	Vitamin A, D, E, K deficiency, Fatty stool	Blood test, fecal fat analysis
Illicit Drugs	AMP/BAR/BUP/BZO/COC/mAMP/MD MA/MTD/OPI/OXY/PCP/TCA/THC	Strip*		Salmonella, E.coli, Lysteria, C. diff, etc.	BSFS (diarrhea), bacteria/toxins	Stool culture
Renal Cancer	Hematuria, urine cytology	Strip, Cytology		Colon cancer	gFOBT, mucoid stool, thin stool, stool DNA	Colonoscopy, CEA, biopsy
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	Future Model			

Legend:
- ▮ (pink) Sensor & Image analysis
- ▮ (yellow) Biochemical analysis
- ▮ (blue) 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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