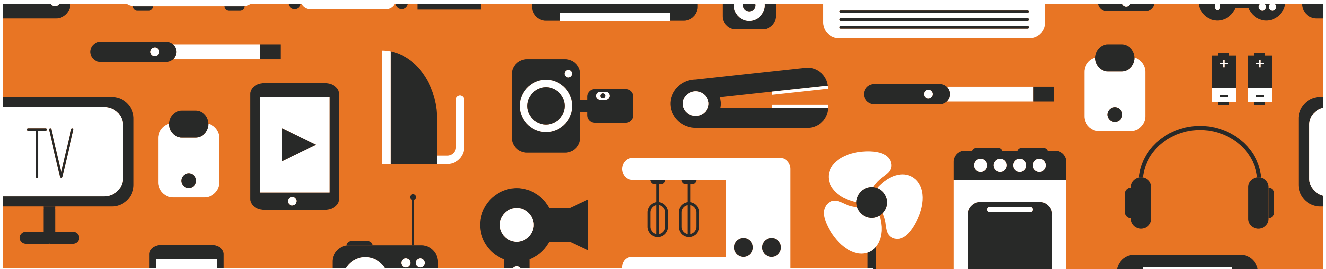

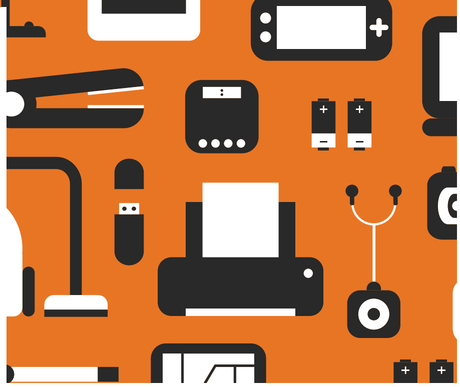

Internet of Telemedicine

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Telemedicine goes back more than 100 years but now has an expanded meaning to include using state-of-the-art technology to assist in a more effective treatment and healing strategy for patients—even if they are in the same room.

Although not referred to as telemedicine, the first occurrence of telemedicine goes back more than 100 years when a Dutch physiologist developed the first electrocardiograph and recorded a patient's heart electrical signals about 1.5 km away from the patient (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2082971/).

Historically, the term *telemedicine* is referred to as remotely delivering patient care. This term has been in use since the 1970s and literally means "healing at a distance."[1] But with the advent of amazing medical technology, telemedicine has an expanded meaning to include diagnosing and treating patients through the use of technology. Although the term still implies that the caregiver is remote, the caregiver may not be far away, just using state-of-the-art technology to assist in a more effective treatment and healing strategy.

Telemedicine's expanded capability can give much credit to the innovations and adaptions made possible by Internet of Things (IoT) technology. In fact, IoT has disrupted the health care industry. Disruptive technologies are those that have significantly changed the way business, industries, and/or consumers function. Other examples of disruptive technologies are blockchain, 3D printing, and virtual reality.

IoT gets more disruptive as time goes on. The number of connected IoT devices has doubled since 2017. As of 2021, there were 12.3 billion connected IoT devices.[2] For example, IoT has changed many ecosystems such as transportation (for example, autonomous vehicles) and the way we live in our homes (for example, smart-home efficiency).

IoT has reshaped health care and, more specifically, has revolutionized telemedicine. The IoT technology has impacted all parts of the health care ecosystem, way before the unprecedented medical challenges that began in 2020. IoT technologies have facilitated "the progress of health care from face-to-face consulting to telemedicine."[2,3]

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It has been integrated in the design of medical devices, robotic-assisted surgery, remote treatment, and monitoring making health care more flexible, adaptable, and accessible, thus changing the way this industry operates.

For example, IoT and robotics have changed rehabilitation, surgery, patient monitoring, and prosthetics.[5] Not only has IoT transformed treatment plans, but it also has improved the way people with chronic conditions manage and have more control of their care.[6] In addition, telemedicine systems are now able to "predict health issues, diagnose, treat and monitor patients" both in and out of the hospital.[7] This is partly due to the development of clinical-grade sensors and sensor networks in hospitals.[5] This article will highlight the IoT impacts and support of the many aspects of telemedicine.

ROBOTIC HEALTH CARE

Surgery

Robotic-assisted surgery has been around since the mid- to late 1980s. It was created to help surgeons overcome limitations of minimally invasive laparoscopic surgeries. With traditional laparoscopy—which was created to decrease postoperative pain and incision size, and to shorten recovery—the surgeon is limited in their range of motion due to lack of articulating instruments. Robotic surgical tools have articulating joints with 360° of rotational movement. Asghar et al.[8] noted that surgical robots have improved laparoscopic surgeries such as urologic pelvic surgery by adding improved visualization and dexterity. The resulting techniques made possible with robot-assisted laparoscopy also benefit the patients with an even faster recovery, decreased pain, lower blood loss, and a shorter hospital stay.[8] Robots have been said to make an average surgeon "better" and a skilled surgeon "a master."

Surgical robots are part of the IoT ecosystem because, simply stated, they use sensors to understand their environment and to move the "things," also called *actuators*. When performing a robot-assisted surgery, the surgeon is able to view with enhanced definition and magnification, which allows for more precise movements to more effectively pinpoint the treatment area, all made possible with the assistance of multiple types of sensors. With conventional "open" or nonminimally invasive surgery, the surgeon is limited to the surgical field, which is below his hands. Robotic surgery allows the surgeon to work "underneath" tissues due to the narrow and fine instruments that can get in spaces the human hand, fingers, and conventional surgical instruments can't.

There are many types of surgical robots used for different purposes. A soft robot system used in remote surgeries can access surgical regions that are a challenge due to the limitations of human-hand reach.[9] The "things" such as sterile injectors, catheter needles, surgical round tip scissors, ablation tools, and so on during a soft robot-assisted surgery are navigated with the help of proximity sensors.[9]

Other surgical challenges are also being addressed with robot-assisted surgical tools. Imagine the difficulty of using robot-assisted surgery when operating on a beating heart[9] or needing exposure to work in the pelvis to address distal ureteral obstructions (blockages in urine tubes).[5] Advances in sensors make these things possible. The main types of sensors include proximity, range, force, and tactile. Here are brief descriptions of each:

- *Proximity sensor*: detects the presence of objects without contact; researchers are working on proximity sensation by developing a system that applies transcutaneous (measured) pulsed electrical stimulation to the fingertips of robotic surgery teleoperators (surgeons using a type of controller) to improve the accuracy of perception of distance to contact[10]
- *Range sensor*: used to calculate the distance between the sensor and a work part
- *Force sensor*: provides real-time haptic (technology that can create an experience of touch by applying forces, vibrations, or motions to the user) feedback to the user
- *Tactile force sensor*: provides the ability to monitor and control haptic feedback; embedded into robotic arms, these sensors are able to communicate the level of grip force applied.

In summary, the sensors described deliver data that are analyzed by the system and used to ultimately move the surgical tools.

Nursing

Initial robotic nurses were introduced to perform tasks that do not interact with patients (30% of nursing tasks) such as delivering patient specimens or delivering admission buckets to clean rooms, allowing more time for nurses to care for patients.[11] More recently, advancements in nursing robots can assist with patient care. For example, adding tactile and proximity sensors to "robot skin" allows a robot to perform other nursing tasks such as lifting and transferring a patient safely.[12]

HEALTH MONITORING

Technology improves accessibility and flexibility of health care services to the public. In addition, patient-wearable medical technology can be effective for telehealth visits to assist a provider in decision making for diagnosis, medication changes, postsurgery consults, second-opinion consults, and even speed up visits at an overloaded emergency room (having a virtual visit with a physician on call while in the emergency department of a hospital).

Prior to IoT medical technology, outpatient care would include periodic snapshots of information gathered at a face-to-face visit with a provider. Using IoT-enabled telemedicine technology, physicians and patients can use monitoring devices that provide continuous data collection to allow a 360° view of a patient's progress and health. Using data collected and stored on the cloud from patient-worn biomedical sensors, analysis algorithms are used to determine and promote improved strategies for health interventions. For example, when a patient wears a continuous glucose monitor or a heart monitor, a caregiver can share the data and intervene, adjust medications, or answer patient questions when necessary. No physical visit is necessary, as the provider can view the data and contact the patient remotely.

Other monitoring advancements were shown and validated by researchers with three use cases: cardiovascular disease, hypertension, and chronic obstructive pulmonary disease. The results showed remote monitoring of patients with these chronic conditions, resulting in an improvement in their self-management and increased patient motivation to adopt a healthy lifestyle.[13] Researchers are also using IoT technology in home-health monitoring as well as cloud computing to improve stroke diagnosis and treatment remotely.[14] Furthermore, ophthalmologists are also beginning to utilize digital innovations such as artificial intelligence, 5G, and IoT to develop remote treatment plans to tackle specific problems such as diabetic retinopathy, macular degermation, glaucoma, and so on.[15]

Real-time monitoring can provide tracking and test result analysis when either patients or caregivers are remote.

In times of crisis, when medical staff is short, remote monitoring is extremely beneficial to all involved. Real-time monitoring can provide tracking and test result analysis when either patients or caregivers are remote. For example, raw data collected using sensors to capture environment (room temperature/humidity), heart function, patient temperature, CO, and CO_2 can be efficiently and quickly analyzed from anywhere.[3]

Telemedicine health monitoring of physiological indicators in addition to treatment is also used for prevention of some conditions. For example, researchers are exploring using machine learning algorithms to monitor an athlete remotely in prevention and monitoring of life-threating conditions (for example, heart disease, brain tumors, and cancer) during training and competition.[4]

REMOTE MEDICAL EVALUATION AND TREATMENTS

IoT and robotics are also being used to provide and transform other health care services such as rehabilitation, prosthetics, and follow-up visits. Examples of rehabilitation, prosthetic, and elderly care research is summarized from Pradhan[5]:

- *Rehabilitation*: When a trained professional is not available or remote rehab care is necessary, limb rehabilitation can be provided with portable rehabilitation devices that include pressure sensors. These help providers to remotely monitor strength and duration of training as well as analyze progress to recommend intensity changes for remote rehabilitation.
- *Prosthetics*: Researchers are working on validating prostheses that are controlled by microprocessors to enable remote configuring by a clinician. Clinicians are also able to evaluate the patient's prosthetic configuration remotely.[16] IoT has also facilitated prosthetic systems that include temperature, pressure, accelerometer, gyroscope, potentiometers (measuring distance), and proximity sensors for the prosthetic "part" to interact with the environment, for example, multifingered robotic hands built with tactile and nontactile sensors to move joints more accurately.
- *Elderly Care:* IoT can support the aging process by providing an environment to support physical, sensory, and cognitive issues such as providing reminders, detecting falls, and continuous care. There are in-home service robots using sensors, radiofrequency identification, GPS, infrared, and wearable sensors, to connect a patient's vital signs to health care professionals and caregivers. These technologies can improve one's quality of life to by extending one's time of independence in their own homes.

Telehealth tools enable a "care anywhere" model. IoT technology has assisted telemedicine in many ways by giving chronically ill patients the real-time information needed for improved quality of life and by enabling providers to get the information needed to remotely deliver patient care, as well as technologies for in-patient treatments such as robotically assisted surgical procedures.

In addition to developing effective and safe new innovations, other challenges and risks need to be addressed by engineers, such as energy consumption between biosensor nodes, timely delivery of remote patient information, and transmitting sensitive data securely, while also ensuring data privacy and integrity.[17] Developers should consider using established cybersecurity, privacy, and risk management frameworks provided by the National Institute of Standards and Technology. These frameworks help to "identify risks and select appropriate controls that support telehealth" integration.[18] Other challenges include data validation, patient acceptance, education, and training of end users on these technologies also need to be considered.[15]

Medical professionals, medical researchers, and technology experts need to continue to collaborate and adapt care models. There are many more telehealth innovations available and being designed and developed. Some medical domains are only scratching the surface, but they will soon be able to take advantage of IoT technology to improve telemedicine opportunities. ■

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