Future Implantable Systems

Ada S. Y. Poon
Electrical Engineering, Stanford University

American physicist and Nobel laureate, Richard Feynman, in his famous lecture from 1959, "There's plenty of room at the bottom," presented a wild idea of swallowable surgeons where tiny surgical robots are put inside the blood vessel, *travel* into the heart, *look* around, and *send* the information back to an external controller. These robots can even perform local operations and might be permanently incorporated in the body for continuous monitoring. The idea seems a science fiction dream. In recent years, however, there is major progress on implantable systems that support most of the functionalities of the swallowable surgeons. Nevertheless, these devices remain mostly restricted to research, in part due to limited miniaturization, power supply constraints, and lack of a reliable interface between implants and the external devices.

Our research aims to address these limitations. We envision that future implants should be small and versatile enough to support extracellular and intracellular level distributed biosensing and localized operations; and implantable systems should become an integral part of minimally invasive diagnostic tools and surgical instruments to attain more accurate diagnosis and enhance the success rate of complicated surgical procedures. There are two major aspects of this vision. First, new functionalities should be introduced to aggressively miniaturize implants to μm-scale such that they can navigate within the body to perform distributed sensing and localized operations. Second, there is a need to establish close interactions and collaborations with medical doctors, radiologists, and biologists so as to identify promising clinical applications for implantable systems.

To address the first aspect, we have developed new understanding on achieving optimal power transfer efficiency for wireless power transmission over biological tissues. We have shown that the optimal frequency for power transfer is much higher than previously thought, and thereby reduced the area of the power receiving coils by more than 100 fold without sacrificing either power efficiency or range. Based on this new theory, we have implemented an integrated power receiver chip with a receive coil that is 100 times smaller in area than previous designs in the literature at the same power transfer efficiency and range. This new understanding also reveals that the regime of operation for optimal power transfer is different from that of current approaches. Electromagnetic fields can be focused to the location of individual implants and improve the transfer efficiency further. In a similar way, by examining the propulsion problem from first principles, we discovered a new propulsion method that circumvents many of the issues with current approaches. Currently, we are developing a micro propulsion system for the implant and a position sensing mechanism such that we can remotely control the movement of the implant.

In collaboration with cardiologists, we are developing a *leadless* defibrillator which consists of a compact endocardial implant of diameter 1 mm and length 5 mm. These implants will be screwed into the right ventricle. They will sense the electrical activities and transfer the sensed data over a wireless link to a subcutaneous implantable cardioverter defibrillator (ICD). The ICD will determine whether pacing is needed. When it is needed, it will issue a pacing order to the endocardial implant via the same wireless link. The endocardial implant will then pace the heart accordingly.

Moving along the direction of extracellular sensing of cardiac muscle, we want to make the implant even smaller to be placed inside biological cells for cellular-level *in vivo* biosensing and cancer monitoring. The goal of this project is to demonstrate that μm-scale wireless sensors are feasible, these sensors can be penetrated into biological cells, and a transceiver system is able to pick up signals from these sensors.