Mixed Reality Enabled Digital Twin For Robot-Assisted Bridge Element Inspection And Maintenance

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Traditional robot-assisted bridge inspection still merely relies on manual operation in line of sight and pilot experiences, which is labor and time-intensive, and susceptible to inaccessible areas and subjective evaluation. Empowered by the advanced 3D sensing, computer vision and AI algorithm, autonomous robotics (such as UAVs, ground robots and underwater robots) provide an unprecedented potential for close-up inspection of the bridge element conditions in an efficient and reliable fashion. Digital twin is digital representations of a physical asset, process or system, which allows us to understand and model its performance as it can continuously update with data from multiple sensors/sources to represent the near-real-time system status without being personal on-site frequently. Augmented reality and devices (AR) e.g. HoloLens, allows virtual overlay of contextual digital information onto a physical-world object such as drones and robots, augmenting the understanding and capabilities of our robotics system in real time. In reality, the UAV and robot tests can be dangerous and costly if crashes happen, and the development and deployment of the robots, inspection route planning and executions are still tedious and segmented with tremendous manual interventions during bridge inspection and structural health monitoring. A mixed reality enabled digital twin modeling framework was proposed and mixed reality interface was implemented in this research for the bridge inspection and maintenance robot development and testing, inspection route planning, and bridge element inspection and maintenance with a virtual prototype of an inspection robot and a target bridge asset. The proposed digital twin approach is able to provide a virtual representation of an inspection robot traversing the target bridge either from design-construction model or 3D scanning of the real-world physical bridge assets within sub centimeter accuracy in the Unity/Gazebo simulation environment. The traversing robot and its Robotics Operating System (ROS) autonomous navigation and obstacle avoidance software will be validated with hardware-in-the-loop simulation and flight tests. The mixed reality was implemented by using a head-mounted device and the anchoring points to virtual overlay the holographic objects built from a georeferenced markup bridge model and an Vicon motion capture system enabled aerial drilling drone with six degrees of physical freedom of movement. Therefore, the corresponding bridge inspection and maintenance robot's route planning can be executed and the flight control algorithm effectiveness and real-time object detection and haptic sensing feedback control performance will be evaluated before field deployment in a 3D mixed reality environment, the robot navigation and path planning as well as the aerial manipulation operation can be tested and optimized before the actual flight operations. The preliminary result shows that the mixed reality platform and digital twin approach provides a promising framework for development and validation of robot autonomous navigation and obstacle avoidance algorithm, path planning algorithm and aerial manipulation for both bridge element in-field inspection and maintenance as well as professional inspector training.