Progress Report on the MUST-UWC Collaboration on *Healthcare 4.0: Contact Tracing and Tracking in Cyber Physical COVID-19 System (CPCS)*

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Project Objective

Under the UMSAEP framework, the collaboration between Missouri University S&T and University of the Western Cape, tagged (MST-UWC), is to jumpstart a cutting-edge research cooperation between Prof. Sajal K. Das (Daniel St. Clair Endowed Chair and Professor of Computer Science at MST) and Prof. Bigomokero Antoine Bagula (Professor and Chairperson, Department of Computer Science at UWC) on the design and development of a cyber-physical system (CPS) and its applications to various fields including healthcare, environmental monitoring, and air/noise pollution. These CPS centred projects are leverage on technologies of industry 4.0 revolution, such as sensor networks, internet of things (IoT), artificial intelligence (AI), machine learning (ML), data analytics (DA), and high-performance computing infrastructure (HPC).

Our synergistic MST-UWC collaboration focused on: (1) CPS design in Healthcare 4.0; and (2) CPS resource management using machine learning techniques. The ongoing collaboration has also resulted in seminars on industry 4.0 and drafts of research articles.

Progress Report

While many activities were planned to be held, including visit exchanges between MST and UWC, due to the COVID-19 pandemic, only the Healthcare 4.0 and seminars on industry 4.0 technologies were realized in the last year. A summary of the activities is given below.

1) CPS Design in Healthcare 4.0:

This project focuses on Contact Tracing and Tracking in Cyber Physical COVID-19 System (CPCS). CPS can be efficiently applied to monitoring of physical systems and processes via sensors, analysis of collected data, followed by a control action. When applied to the current global epidemic, CPS principles can be effectively used in conjunction with disease transmission (epidemiological) modelling to efficiently predict disease-spread and provide useful insights that can help curve the spread of the disease and decision support to health practitioners for the efficient management of the pandemic. The key components of this project are collection and digitization of COVID-19 data, information dissemination and federation on HPC including Cloud and Fog, information processing using AI, ML, DA and visualization to gain useful insights into the disease identification, dissemination and mitigation, and societal and economic impact assessment of COVID-19.

This project additionally involved an associate professor (Tony T. Luo), a postdoc (Debraj De) and M.S. student (Henry Wong) at Missouri S&T; and several colleagues and post-graduate students at UWC, including Olasupo Ajayi and Hloni Nwanati. The team conducted biweekly meetings via Zoom to exchange ideas and discussed research problems and solutions including outlines and drafts of research articles.

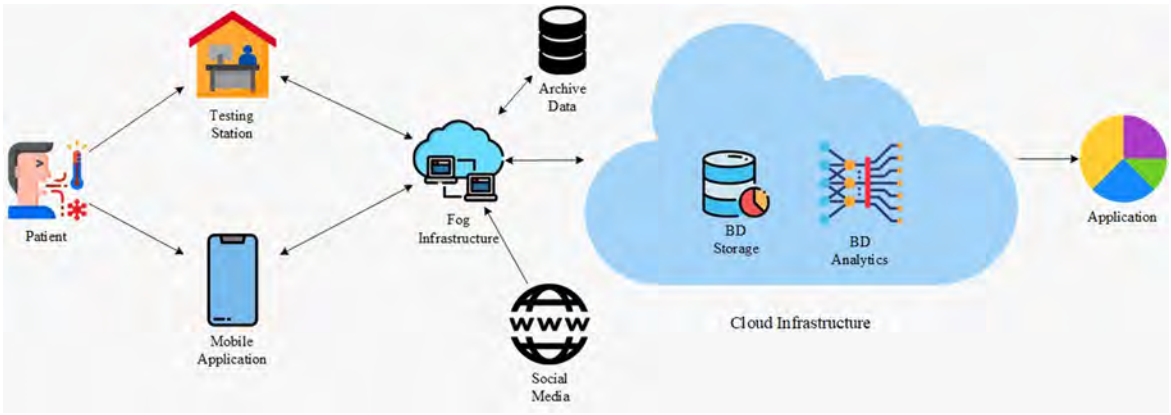

Figure 1. Cyber-Physical COVID-19 System (CPCS) Management Scenario

Figure 1 depicts a simplified scenario of our proposed Cyber-Physical COVID-19 System (CPCS) management. i) A patient going through a testing station or using mobile app gets information on the pandemic and/or provide information on COVID-19 related health. ii) A Fog infrastructure where the testing station and mobile app data as well as information collected from social media and archiving systems are transmitted for preprocessing/prescreening. iii) A Cloud infrastructure endowed with big data storage and processing capabilities collects and federates the information coming from different fog infrastructures and applies federated learning to get useful insights for different applications. iv) Applications where these insights are visualized, analyzed and decisions are taken about the evolution of the pandemic and its management. Note that this CPCS management scenario also reveals a multi-layer architecture, namely the "data capture layer" consisting of the patient, testing station and mobile application, which is below the "fog layer" involving the fog computing infrastructure along with social media and archiving systems, which is below the "cloud layer", which is below the "service/application layer".

Products: COVID-19 adversely affected the progress of this project. Planned visits by the PIs had to be cancelled, as well as those of the post-graduate student who had to work from home with poor connectivity and resources. This forced a review of the project to the preparation of two articles to be submitted to journals. These articles were to focus on: i) a review of cyber physical human systems for COVID-19, and ii) application of federated machine learning on COVID-19 data. While working on the two papers, members of the two teams have been meeting every two weeks to report on the progress. The papers are still in the works. It is hoped that in the coming year, when the travel restrictions are loosened, the project can resume in earnest. While the focus of the review paper lies in a systematic review of different IT mechanisms and technologies for the management of COVID-19 pandemic, the second paper's focus is on designing a new federated learning model for the identification of COVID-19 pandemic.

2) CPS Management Techniques:

Figure 2 depicts a simplified scenario of our proposed Cyber-Physical Environment System (CPCS) management. It consists of sensor devices located at the edge of the system to collect environmental data and send the data to a fog infrastructure located close to the users where different processes, including real sensor virtualization and/or security surveillance in terms of anomaly detection, may be executed on the data before transport to a cloud infrastructure where bid data processing is performed for global management and planning related to the application being considered. Specifically, we investigated two important research challenges, namely CPS resource allocation and CPS security, as summarized below.

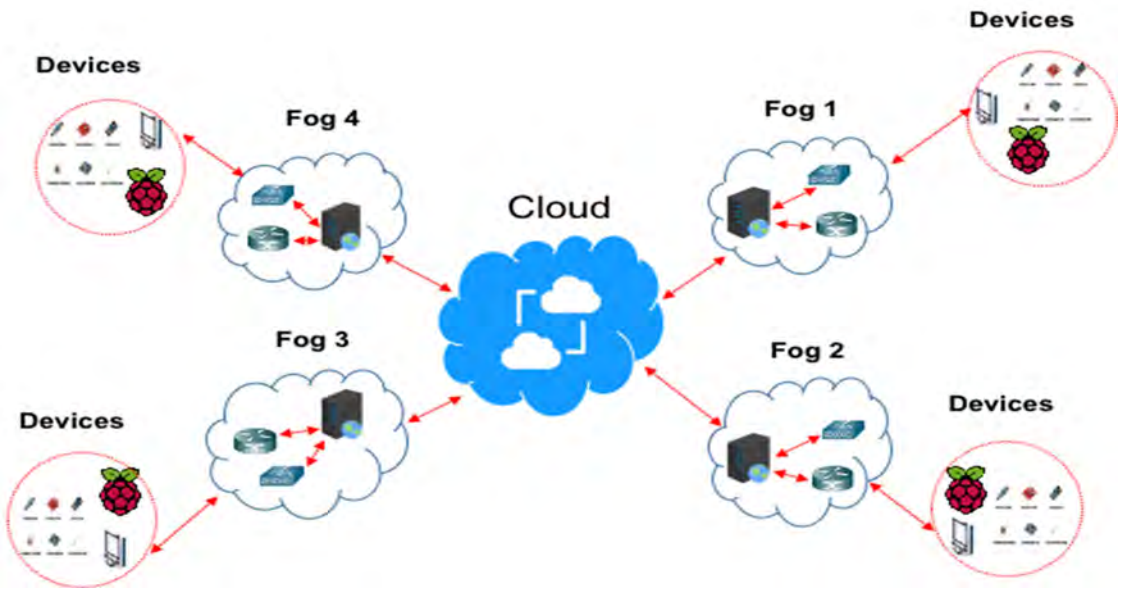

Figure 2. Cyber-Physical Environment System (CPES) Management Scenario

Products: The CPS resource allocation focuses on application of scheduling and resource management mechanisms and heuristics in IoT and sensor-based healthcare systems. The UWC team got a paper accepted in the EAI Africomm 2021 conference. On the CPS Security front, the focus is on securing next generation networks, such as CPS-IoT subsystems and software defined networks (SDNs). Three papers have been planned for this research area. The first on focuses on modelling distributed denial of service (DDoS) attacks in CPS-IoT systems using machine learning models, is about 70% complete and plans are on the way to submit to a journal in the new year. The second one is a review paper surveying various attack models and solutions for SDN systems. Finally, the third paper is on defending and maintaining the safety of IoT subsystems (sensor network's architecture) using graph theory and zero-touch networks.

3) Seminar Series on Industry 4.0 Technologies:

This is an on-going seminar series of put together by Prof. Sajal Das at Missouri S&T. Many of these seminars were also attended by members of Prof. Antoine Bagula's team. This has been a tremendous professional and academic developments of both teams at MST and UWC.

Summary: The UMSAEP framework acted as a catalyst to jumpstart a close cooperation and collaboration between the Computer Science Departments at MST and UWC. This has led to synergistic team and trust building, leading to biweekly meetings and exchange of research ideas on a sustained basis in the last 1.5 years. Several papers are in the works. Prof. Bagula is considering the appointment of Prof. Das as a Distinguished Visiting Professor in Computer Science at UWC. One of Prof. Bagula's researchers is planning on a few month's visit to Prof. Das' lab in 2022.