# Research Statement

My research goal is twofold: (1) advance the scientific knowledge of Artificial Intelligence and the engineering foundations of robotic systems; and (2) develop practical intelligent systems that have an impact on our society. There are many tasks (e.g., driving and game playing) that are manageable for humans but surprisingly difficult for machines with current technology. I am interested in building intelligent machines that excel in these tasks.

At UNIST, I found *the Agents and Robotic Transportation Lab*, which dedicates to Artificial Intelligence and Robotics research. The objective of my lab is to scientifically investigate the foundations of artificial intelligence and robotic systems for decision making and problem-solving, using techniques such as machine learning, automated reasoning, and game theory. Apart from traditional topics in AI and Robotics, my lab also focuses on real-world applications in transportation and logistics domains.

In the past decade, Artificial intelligence enjoys a renaissance period due to the advances in machine learning. A Korean team won the DAPRA robotic challenge in 2015, proving that deploying robots to challenging rescue missions such as nuclear meltdowns is not a dream. The development of autonomous vehicles prompts us to ask when, not whether, autonomous vehicles will be deployed to the real-world traffic. All these breakthroughs happen almost at the same time. However, these technological revolutions have not ended yet---there are new developments in the intersection of these research areas from time to time. Our lab sets out to develop technology that spans all these areas.

At UNIST, I have been working extensively in robotics and transportation systems. In this section, I will present my research plans in three different research directions: (1) multirobot systems, (2) intelligent transportation systems, and (3) security robots.

**Multirobot Systems.** In multirobot systems, a group of intelligent robots perceive and act in a shared environment to accomplish tasks collectively. Multirobot systems have garnered significant attention recently. This research area is rather broad, and there are many interesting research topics. In my lab, several lines of research will continue to be pursued.

First, we have been conducting research in autonomous ground robots such as autonomous vehicles. Fully autonomous vehicles are technologically feasible with the current generation of hardware, as demonstrated by recent robot car competitions. My two research directions on autonomous vehicles are: (1) how to enhance the safety of autonomous vehicles? (2) how to leverage the autonomy of autonomous driving to improve the traffic flow and avoid traffic congestion. Previously, our lab has received a research grant from Hyundai to study how to enhance autonomous driving safety. In the project, my collaborator and I developed an accident prevention system, which utilizes the dashcam of a vehicle can predict upcoming traffic incidents while driving and then generate evasion plans to avoid collision. After the project, I further extend the framework to make it work for other multirobot systems, such as generating backup plans in cooperative transportation of human-robot teams. I have also developed many techniques to push forward this research agenda, including developing a

team of semi-autonomous vehicles for autonomous intersections. In the future, we will continue to study how a team of autonomous vehicles cooperate to make urban transportation systems more efficient and safer and address the challenges related to assuring safety during autonomous robot operations in uncertain environments.

Second, we have been researching in autonomous aerial robots. Most of the existing drones are controlled by humans directly, with either FPV or direct line-of-sight. Building a fully autonomous drone that can fly by itself remains a holy grail of the field. The technical challenge of building a fully autonomous drone is tremendous due to drones' small payload and limited battery life. Since 2016, my students and I have been taking part in autonomous drone racing competitions. Our latest entry to the competition in 2018 has been quite successful---it is one of the few drones that can complete the entire course in the competition. My long-term goal is to build and program a fully autonomous drone that can fly in a cluttered indoor environment to perform some tasks (e.g., delivering an object to a target location). These drones will enable some important applications, e.g., drone delivery and taking part in disaster rescue missions. We have been focusing on extending the flight range of delivery drones by machine learning and how to fly extremely fast in a very tight environment with obstacles. In addition, we are currently studying how a drone swarm can carry out a mission, such as collecting resources as a team. The era of fully autonomous drones has just begun, and my lab is fully embracing it.

Third, we are interested in developing mobile robots for manufacturing automation. Recent advances in artificial intelligence offer new opportunities to improve productivity and reliability for automated factories. We like to study many aspects of manufacturing automation, and we start with the most common component first: conveyors. High-speed conveyors are the key to connect different pieces of machinery so that automation can be deployed. We believe conveyors can be much more 'intelligent' and can help increase a factory's efficiency. At UNIST, we have been studying a new type of robot called mobile conveyors. We confer mobility to existing conveyors so that the conveyors can move around to connect different parts of factories. Then new manufacturing processes can be deployed quickly by connecting various pieces of production machinery together. The mobile conveyors are suitable for building an agile manufacturing process that can adapt to the customer's demand. We also proposed a new concept called mobile workstations, which combine production machinery with mobile platforms so that the production machinery can move around to serve different parts of a factory or in an office environment. In the future, we like to push forward a new field of robotics called high-throughput robotic systems, which optimize for the number of jobs a robot can handle instead of the speed of handling one job.

To promote my work in the robotics community, I have organized a workshop on Machine Learning in Planning and Control of Robot Motion Workshop (MLPC) in ICRA 2018, one of the top conferences in Robotics, and I have served as the guest editor in IEEE Intelligent Systems, one of the premier magazines in Artificial Intelligence. Currently, I have been serving as a co-chair of the IEEE Robotics and Automation Society Technical Committee on Algorithms for Planning and Control of Robot Motion.

**Intelligent Transportation Systems.** Transportation systems are good examples of multiagent systems in which vehicles have to coordinate with others, even though each of them

minimizes their travel times regardless of the overall system efficiency. The demand for transport keeps increasing, and hence an efficient transportation system is extremely important for our society's long-term sustainability. Since I was a postdoc at UT Austin, I have investigated a new kind of transportation infrastructure for autonomous vehicles. I have continued the work at UNIST.

The recent robotic car competitions (e.g., the DARPA Urban Challenge) and demonstrations have shown that autonomous vehicles, or driverless vehicles, have the potential to improve safety and mobility, avoid driving-related stress, improve fuel efficiency, and reduce emissions. Looking ahead to the time when autonomous cars will be common, my colleagues and I studied how to utilize autonomous vehicles' capacity to make transportation systems much more efficient. In particular, I worked on a new intersection control protocol that outperforms optimized traffic signals. I also studied the problem of contraflow lane reversal and the liveness of transportation systems. At UNIST, I have continued the research and published some papers on these topics. In the future, I will expand the scope of these projects and explore opportunities for fuel-saving and better traffic control.

While the control of autonomous vehicles such as the Google Driverless Car is good enough for driving on today's roads, more precise control can lead to better utilization of road surfaces and reduce traffic congestion. Hence, I am investigating different types of vehicle controllers that can improve transportation efficiency. At UNIST, I devised a highly efficient setpoint scheduler for the PID controllers of the brake and throttle actuators of our autonomous vehicle to control the vehicle to arrive at an intersection at a given time and velocity. My works have demonstrated that the synergy of the controller of autonomous vehicles and intersection control protocols can lead to more traffic throughput with less traffic congestion. In the future, I will continue to investigate other aspects of autonomous vehicle control that can improve traffic conditions.

Transportation systems are safety-critical systems—any error that can cause human injury is unacceptable. How to properly test these systems is an important subject. Previously, I developed a mixed reality simulation platform to check whether real autonomous vehicles can safely traverse an intersection under the AIM protocol, and a small robotic car platform for testing and evaluating autonomous driving at intersections. At UNIST, I got a research grant from the National Information Society Agency (NIA) in South Korea to build a traffic speed and congestion prediction system in Ulsan. The system has been successfully deployed and used by TBN, a radio broadcast station for traffic and weather information in Ulsan. Our system has been used to redirect traffic when there are traffic accidents at some spots in Ulsan. In the future, I am interested in developing better platforms for the most realistic tests of traffic control systems, based on which I will develop techniques for automatic error detection and recovery to prevent traffic accidents and minimize the scale of crashes when errors occur.

**Security Robots.** In the next decade, we will witness the rise of security robots. Some new startups such as Knightscope have already designed robots to supplement human security guards and help law enforcement. How to schedule a team of robots to protect important national infrastructures is a challenging task for police and security agencies worldwide---a challenge that is exacerbated by the threat of terrorism. At UNIST, I got a research grant from

NRF to work on security robots. The objective of this project is to develop scheduling algorithms for robot teams in security tasks.

Since the mid-2000s, the study of game theory for security tasks has been a hot topic in artificial intelligence. For example, to fight against terrorists, a team of researchers at the University of Southern California developed a security system for controlling the police's patrolling schedule at Los Angeles International Airport. The goal of my NRF project is to advance these systems for security tasks. We aim to address the challenges: given a finite number of robots and limited human resources, how can we schedule the robots to maximize a robot team's coverage for security tasks? Furthermore, how can we incorporate human intelligence in robotic patrolling systems to perform the same set of tasks as human guards? We expect our research will lead to the practical implementation of telepresence robots, scheduling algorithms, and the corresponding commanding center that can be deployed in some national facilities such as airports. I believe my lab is the best place in Korea to study security robots given our backgrounds in robotics, game theory, and AI.

At UNIST, I have made substantial contributions to Artificial Intelligence and Robotics as I am a regular author in top-tier publication venues, and I have actively provided services to the international research community. The impact of my work is highlighted by my citation rates. I have established three lines of research at UNIST, each with success in getting funding in the past. I have trained several graduate students at UNIST, and I believe some of my students will become successful technology innovators in the future. My background in multirobot systems, intelligent transportation systems, and game theory puts me in a unique and empowered position to conduct multidisciplinary research. My lab is unique in South Korea, and most of my research can lead to real-world applications that can generate economic growth in the country. I look forward to continuing my work to achieve my ultimate goal: the creation of intelligent machines that can relieve mankind of the last bit of manual labor and assist all kinds of intellectual endeavors.