FRUGAL SENSING AND COMPUTE USING AI/ML FOR URBAN SUSTAINABILITY

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by

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To Everyone in the Past, Present and Future

For making me exist and pursue a PhD in a small moment of the grand time.

Certificate

This is to certify that the thesis titled **Frugal Sensing and Compute using AI/ML for Urban Sustainability**, submitted by **Mr. Sachin Kumar Chauhan**, to the Indian Institute of Technology, Delhi, for the award of the degree of **Doctor of Philosophy** in Computer Science & Engineering, is a record of bonafide work carried out by him under my guidance and supervision at the Department of Computer Science & Engineering, Indian Institute of Technology Delhi. The contents of this thesis, in full or in parts, have not been submitted elsewhere for the award of any degree or diploma.

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If you want to shine like a sun, first burn like a sun.

– A.P.J. Abdul Kalam

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Those who can imagine anything, can create the impossible.

– Alan Turing

Sachin Kumar Chauhan

Abstract

The Industrial Revolution was a turning point in human history which influenced almost every aspect of life. This has improved the human way of living in many ways, but has also induced many negative side effects on human society at large. While the advancement of sophisticated technologies for transport of people and goods, and the efficient processing in the factories, pave way to reduce many scarcities, the congestion on the roads and the induced air/water/noise pollution impacted the humans in a drastic way. With the recent explosion in populations across countries, the consumption of goods and services have never been so high, and the side effects of the development are worse than never before.

Various governmental and public institutions around the world, supported by researchers and domain experts, have been working hard to reduce such side-effects. With the two problems of air pollution and traffic congestion being highly interlinked, they are commonly studied and analyzed together [1, 2, 3, 4, 5, 6, 7, 8] and are practically associated [9, 10, 11]. In the era of AI/ML, the efforts to improve the detection and mitigate the extreme impacts got a new direction. Sophisticated AI methods can help us detect the causes and effects of pollution indicating the authorities to act sooner. Newer AI based solutions can emerge to solve the traffic congestion leading to effective transportation. These solutions need an array of sensing devices alongside high computation requirements. The deployments of such AI based solutions on a large scale would cost highly. While developed nations can invest heavily on these solutions, the large part of humanity living under developing and under-developed economies could not scale on the costly advancements.

In this work, we aim to improve the situation of deploying the AI advancements at scale in the under-developed economies by providing frugal, i.e. efficient and cost-effective, solution approaches to the societal problems of air pollution analysis & mitigation and traffic congestion control using limited sensing devices and efficient computing. AI solutions that need less sensors and limited compute can be effectively deployed on low-cost edge devices, allowing the scaled deployment feasible for countries with limited budget.

Abstract

औद्योगिक क्रांति मानव इतिहास में एक महत्वपूर्ण मोड़ थी जिसने जीवन के लगभग हर पहलू को प्रभावित किया। इसने कई तरह से मानव जीवन जीने के तरीके को बेहतर बनाया है, लेकिन इसने मानव समाज पर कई नकारात्मक दुष्प्रभाव भी डाले हैं। जहाँ लोगों और वस्तुओं के परिवहन और कारखानों में कुशल प्रसंस्करण के लिए परिष्कृत तकनीकों की उन्नति ने कई अभावों को कम करने का मार्ग प्रशस्त किया, वहीं सड़कों पर भीड़भाड़ और प्रेरित वायु/जल/ध्वनि प्रदूषण ने मनुष्यों को बहुत ज़्यादा प्रभावित किया। हाल ही में विभिन्न देशों में जनसंख्या में हुए विस्फोट के साथ, वस्तुओं और सेवाओं की खपत पहले कभी इतनी अधिक नहीं रही, और विकास के दुष्प्रभाव पहले से कहीं ज़्यादा खराब हैं।

शोधकर्ताओं और डोमेन विशेषज्ञों द्वारा समर्थित दुनिया भर के विभिन्न सरकारी और सार्वजनिक संस्थान ऐसे दुष्प्रभावों को कम करने के लिए कड़ी मेहनत कर रहे हैं। वायु प्रदूषण और यातायात भीड़भाड़ की दो समस्याओं के आपस में अत्यधिक जुड़े होने के कारण, उनका आमतौर पर अध्ययन और विश्लेषण एक साथ किया जाता है और व्यावहारिक रूप से वे एक दूसरे से जुड़े हुए हैं। AI/ML के युग में, पता लगाने में सुधार करने और चरम प्रभावों को कम करने के प्रयासों को एक नई दिशा मिली है। परिष्कृत AI विधियाँ हमें प्रदूषण के कारणों और प्रभावों का पता लगाने में मदद कर सकती हैं, जिससे अधिकारियों को जल्द ही कार्रवाई करने का संकेत मिलता है। यातायात भीड़भाड़ को हल करने के लिए नए AI आधारित समाधान सामने आ सकते हैं, जिससे प्रभावी परिवहन हो सकता है। इन समाधानों के लिए उच्च संगणना आवश्यकताओं के साथ-साथ संवेदन उपकरणों की एक सरणी की आवश्यकता होती है। बड़े पैमाने पर ऐसे AI आधारित समाधानों की तैनाती में बहुत अधिक लागत आएगी। जबकि विकसित देश इन समाधानों पर भारी निवेश कर सकते हैं, विकासशील और अविकसित अर्थव्यवस्थाओं में रहने वाली मानवता का बड़ा हिस्सा महंगी प्रगति का लाभ नहीं उठा सकता है।

इस कार्य में, हमारा उद्देश्य सीमित संवेदन उपकरणों और कुशल कंप्यूटिंग का उपयोग करके वायु प्रदूषण विश्लेषण व शमन और यातायात भीड़ नियंत्रण की सामाजिक समस्याओं के लिए किफायती, यानी कुशल और लागत प्रभावी समाधान दृष्टिकोण प्रदान करके अल्प-विकसित अर्थव्यवस्थाओं में बड़े पैमाने पर AI उन्नति को लागू करने की स्थिति में सुधार करना है। AI समाधान जिन्हें कम सेंसर और सीमित कंप्यूटिंग की आवश्यकता होती है, उन्हें कम लागत वाले Edge डिवाइस पर प्रभावी ढंग से तैनात किया जा सकता है, जिससे सीमित बजट वाले देशों के लिए बड़े पैमाने पर तैनाती संभव हो सके।

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