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COMPUTER VISION APPLICATIONS FOR SMART CITIES USING REMOTE SENSING DATA

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With the rapidly growing urbanization level overpopulation became one of the main challenges for the municipalities, country economics, and governmental management. Many issues concerning waste management, city resource planning, air pollution, traffic and transportation overload and population health issues challenge existing infrastructures. Smart city aims to improve people's lifestyle, create more sustainable environments and make it easier to manage all these processes by municipalities and governments. The application of AI and computer vision techniques can solve smart city problems (surveillance, area coverage, land usage and land coverage, damage monitoring, fire detection, etc.) that weren't possible or easy to do a few years ago.

Here, we are reviewing deep learning and computer vision applications for smart cities using remote sensing data. Moreover, we present 2 types of data sources for creating datasets to solve smart city problems for cities in Armenia. The first type is potential data sources that can be collected through the efforts of the municipality, the second type is open-source data ready to be used for the solutions below.

First, historical data from 3 different satellites were used to calculate available open-source data that can be used to apply deep learning algorithms. Next, for each type of data and each smart city task, the most convenient deep learning methods were found and described. All techniques were summarized in Table 1.

Key words: *Smart city, computer vision, deep learning, remote sensing, artificial intelligence*

Introduction

Based on the World Bank population dashboard, the world population in 2021 is 7.8 billion. Moreover, the urbanization level in 2020 was 56.15%.[1] Based on the UN Economic and Social Affairs report in 2050 the level will reach 68%.[2] Due to overpopulation in existing cities municipalities are not ready to defeat different problems that high urbanization level brings. Many issues concerning waste management, city resource planning, air pollution, traffic and transportation overload, and population health issues challenge existing infrastructures.[3]

[1] Urban population (% of total population). (n.d.). The World Bank. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

[2] World Urbanization Prospects The 2018 Revision, https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

[3] Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Pardo, T. A., & Scholl, H. J. (2012). Understanding smart cities: An integrative framework. In Proceedings of the 45th Annual Hawaii International Conference on System Sciences, HICSS-45 (pp. 2289-2297). [6149291] (Proceedings of the Annual Hawaii International Conference on System Sci-

Nowadays cities are confronting these challenges and trying to figure out new, revolutionary and smart ways to manage arising and existing issues that overpopulation brings. Although the smart city concept is becoming more and more trendy among researchers, there is no clear definition of what this paradigm represents. Paskaleva K.A. (2009) defines a smart city as one that takes advantage of the opportunities offered by ICT (Information and Communications Technologies) in increasing local prosperity and competitiveness – an approach that implies integrated urban development involving multi-actor, multi-sector and multi-level perspectives.[4] A city "connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city."[5] A city "combining ICT and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability."[6]

In 2012 Chourabi[3] represented a whole new framework that explains smart city concepts, and based on the framework there are 8 critical factors that can help to create new smart city initiatives: management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment.[7]

As we can see above in different publications, smart city concepts are described differently, but one thing is common. Most of the researchers bring the importance of ICT in developing and implementing smart city concepts in city infrastructure. In Chourabi's framework technology is one of the 8 factors that can affect the development of the city.

As was mentioned before ICT is one of the game-changer in city planning, it has a huge impact on the development and implementation of the smart city concept. Technologies like sensors, IoT (Internet of Things), networks, and algorithms can make cities smarter.[8] Those technologies can have a huge impact on all different infrastructures of the city like city administration, education, healthcare, public safety, real estate, transportation, utilities. In 2010, Harrison

ences). IEEE Computer Society. https://doi.org/10.1109/HICSS.2012.615

[4] Paskaleva K. A. (2009), Enabling the Smart City: The Progress of City E-Governance in Europe. International Journal of Innovation and Regional Development.

[5] Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. IBM Journal of Research and Development, 54(4).

[6] Toppeta, D. (2010). The Smart City Vision: How Innovation and ICT Can Build Smart, "Livable", Sustainable Cities. The Innovation Knowledge Foundation.

[7] Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Pardo, T. A., & Scholl, H. J. (2012). Understanding smart cities: An integrative framework. In Proceedings of the 45th Annual Hawaii International Conference on System Sciences, HICSS-45 (pp. 2289-2297). [6149291] (Proceedings of the Annual Hawaii International Conference on System Sciences). IEEE Computer Society. https://doi.org/10.1109/HICSS.2012.615

[8] Sánchez-Corcuera R, Nuñez-Marcos A, Sesma-Solance J, et al.(2009) Smart cities survey: Technologies, application domains and challenges for the cities of the future. International Journal of Distributed Sensor Networks.

et al. mention the importance of operational data, which is a combination of data extracted from traffic, power consumption and other sources, in order to optimize operations. In their work three points are mentioned as the most important features of smart cities: (1) the near-real-time data obtained from physical and virtual sensors, (2) the interconnection between different services and technologies inside the city, and (3) the intelligence from the analysis of the data and the process of optimizing and visualizing it.[9] Some researchers stress the importance of data gathering, as a starting point for creating a smart city. Then this data can be used to provide services.[10]

Visual data for Smart City Problems

Many definitions presented above show that ICT is one of the keys to the success of making a city smart. But data gathering is only a minor part of the whole process. Gathered data can be used differently: (1) visualization mechanisms like dashboards for different e-government departments,[11] (2) video streamings from surveillance cameras for safety reasons, [12]-[13] (3) monitoring systems for buildings and roads,[14] (4) sensors for transportation improvements[15].

A huge part of the data for the smart city can be visual data gathered from (1) surveillance cameras, (2) city cameras, (3) UVA, (4) Satellites, etc. Visual data can be used for data visualization and AI in different areas.

One of the most useful data sources can be aerial imageries, which gather remote sensing data. "Remote sensing is the practice of deriving information about the Earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum reflected or emitted from the Earth's surface".[16]

Remote sensing data is collected with the help of special cameras which

[9] Harrison, Colin & Eckman, Barbara & Hamilton, R. & Hartswick, P. & Kalagnanam, Jayant & Paraszczak, J. & Williams, R.. (2010). Foundations for Smarter Cities. IBM Journal of Research and Development

[10] Al-Hader M, Rodzi A, Sharif AR, et al. (2009) Smart city components architecture. In: International conference on computational intelligence, modeling and simulation, pp.93–97. New York: IEEE.

[11] Jing, Changfeng & Du, Mingyi & Li, Songnian & Liu, Siyuan. (2019). Geospatial Dashboards for Monitoring Smart City Performance. Sustainability.

[12] Nigam N. and Kroo I., (2008), Persistent Surveillance Using Multiple Unmanned Air Vehicles," IEEE Aerospace Conference.

[13] Bagula A., Tuyishimire E., Wadepoel J., Boudriga N. and Rekhis S., (2016), Internet-of-Things in Motion: A Cooperative Data Muling Model for Public Safety, Intl IEEE Conferences on Ubiquitous Intelligence & Computing, Advanced and Trusted Computing, Scalable Computing and Communications, Cloud and Big Data Computing, Internet of People, and Smart World Congress, pp. 17-24.

[14] Li D., Shan J., Shao Zh., Zhou X. and Yao Y. (2013) Geomatics for Smart Cities - Concept, Key Techniques,and Applications, Geo-spatial Information Science.

[15] Nikitas A.; Michalakopoulou K.; Njoya E.T.; Karampatzakis D. (2020) Artificial Intelligence, Transport and the Smart City: Definitions and Dimensions of a New Mobility Era. Sustainability.

[16] Campbell J. B. and Wynne R. H., (2011) Introduction to Remote Sensing. Fifth Edition., The Guilford Press, pp. 662.

measure reflected and emitted radiation of an area at a distance. They use different technologies like photogrammetry or LiDAR sensors to find fingerprints of objects on the Earth's surface. Based on the type and the used technology these cameras can be placed on:

- Satellites and airplanes and can collect images of very large areas on the Earth's surface
- Sonar systems on ships can scan the ocean floor without reaching the bottom,
- Cameras on satellites can be used to capture temperature changes in oceans.

Types of remote sensing data differ depending on the camera type and where it will be placed. Those are different types of remote sensing data:

- Light Detection and Ranging (LIDAR)
- Radio Detection and Ranging (RADAR)
- Unmanned Aerial Systems
- Hyperspectral Imagery
- Thermal Imagery
- Aerial Photography

LIDAR cameras use laser signals to capture objects on the surface of the earth, RADAR systems work with radio waves instead of a laser. The third type uses Unmanned Aerial Vehicles or other similar technologies to capture images from the bird's height. Hyperspectral Imageries analyze a wide spectrum of light instead of capturing images in RGB. Thermal systems use heat to identify and visualize objects. Aerial images are very similar to UAS images, the main difference is that aircrafts, rockets, or other spacecraft are used to capture images.

Machine Learning and Computer Vision application in smart cities

Remote sensing data are collected in huge amounts. The correct use of this amount of remote sensing data can be a solution to various types of smart city problems. And part of these solutions can be found with the help of AI and machine learning techniques. Early applications of AI in remote sensing machine learning algorithms (SVM, ensemble models) were used, nowadays the research involves more and more applications of deep learning. First damage detection, classification, and localization problems are solved with algorithms like SVM, later CNNs as well.[17] A huge amount of smart sensors and IoT data was gathered in the sector of energy consumption and mobility where classical machine learning algorithms are more useful.

In 2020, Cugurullo and co suggest three categories of urban artificial intelligence. The first one is associated with autonomous cars, which can result in

[17] Luckey, Daniel & Fritz, Henrieke & Legatiuk, Dmitrii & Dragos, Kosmas & Smarsly, Kay. (2020). Artificial intelligence techniques for smart city applications.

many urban changes like decreasing traffic, energy use, etc. The second category is robotics, which can improve and fasten many mechanical processes. And last but not least is the city brain which is a monitoring mechanism that collects data from different IoT sensors, analyzes the data and creates more data-driven decision-making processes.[18]

Deep learning techniques are one of the most popular ones when it comes to AI in smart cities. The subfield of it is convolutional neural networks which can be very effective in solving different computer vision techniques. CNNs are the state of the art for image data. Aerial, remote sensing imageries, surveillance videos can be input data for computer vision models. Classification and object detection networks can be used for rescue monitoring, destruction monitoring, area coverage calculations, environment mapping, and surveillance. Drone data can be used in smart parking, fire detection, environmental clean-up, agricultural monitoring, etc.[19]

City cameras can be used in authentication in different urban areas (subways, airports, and other public places). For security reasons, car license plate identification and face recognition techniques can be applied.[20] Calculating traffic volume and driving quality estimation can be done using UAV data. Siamese networks can be used in image registration problems.[21]

Problem Type	**Computer Vision Technique**	**Remote Sensing Data Type**	**Related Literature**
Rescue Monitoring	Object detection, segmentation	UAV, aerial images	Jing, Changfeng & Du, Mingyi & Li, Songnian & Liu, Siyuan. (2019) [11]
Area Coverage, Land Usage and Lang Coverage (LULC)	Object detection, segmentation	UAV, aerial images, satellite images	Ma L, Liu Y., Zhang X, Ye Y., Yin G., and Johnson, B.,(2019) [21]
Damage Monitoring	Classification, object detection	UAV, city cameras	Jing, Changfeng & Du, Mingyi & Li, Songnian & Liu, Siyuan. (2019) [11]
Surveillance	Classification,	City cameras,	Nigam N. and

[18] Cugurullo, Federico, (2020), Urban Artificial Intelligence: From Automation to Autonomy in the Smart City. Frontiers in Sustainable Cities.

[19] Ismail A, Bagula BA, Tuyishimire E., (2018), Internet-Of-Things in Motion: A UAV Coalition Model for Remote Sensing in Smart Cities. Sensors (Basel).

[20] Ershad F., Shervan. (2019). Computer Vision in Smart City.

[21] Ma L, Liu Y., Zhang X, Ye Y., Yin G., and Johnson, B.,(2019). Deep learning in remote sensing applications: A meta-analysis and review. ISPRS Journal of Photogrammetry and Remote Sensing.

	object detection, anomaly detection	UAV	Kroo I., (2008)[12] Bagula A., Tuyishimire E., Wadepoel J., Boudriga N. and Rekhis S., (2016)[13]
Smart parking	Classification, object detection	City cameras, UAV	Dixit M., Srimathi C., Doss R., Loke S., Saleemdurai, M.A.. (2020) [22]
Fire Detection	Classification	City cameras, UAV	Chunyu Y., Zhibin M., Xi Zh., (2013)[23]
Agricultural monitoring	Object detection, Segmentation	UAV, aerial images, satellite images	Jing, Changfeng & Du, Mingyi & Li, Songnian & Liu, Siyuan. (2019) [11]
People Authentication	Object detection, Siamese networks, Few shot learning	City cameras	Ershad F., Shervan. (2019)[20]
License plate detection	Object detection	City cameras, UAV	Ershad F., Shervan. (2019)[20]
Drivers Behavior Estimation	Anomaly detection	City cameras	Ershad F., Shervan. (2019) [20]
Image registration	Siamese network, Few shot learning	UAV, aerial images, satellite images	Ma L, Liu Y., Zhang X, Ye Y., Yin G., and Johnson, B.,(2019) [21]

Table 1: Summary of computer vision application with remote sensing data for smart cities

Implementation for Yerevan

As was mentioned above there are 4 main remote sensing data sources that can be used for implementing computer vision techniques to solve smart city problems: UAV, city cameras, aerial images and satellite images. To collect UAV and aerial images some governmental funds and initiatives are needed. That's why for the rest of the paper we will discuss only accessible and existing data sources. Existing data sources for Yerevan are city cameras and satellite images. According to a 26.08.2020 report from the Police of RA states, there

[22] Dixit M., Srimathi C., Doss R., Loke S., Saleemdurai, M.A.. (2020). Smart Parking with Computer Vision and IoT Technology.

[23] Chunyu Y., Zhibin M., Xi Zh., (2013).A Real-time Video Fire Flame and Smoke Detection Algorithm, Procedia Engineering.

are 150 crossroad cameras in Yerevan. Many other cameras are placed from Yerevan Municipality showing aerial views of the Republic Square, Sasuntsi David Square, Cascade complex, North Avenue, Mashtots park, Charles Aznavour, and Garegin Nzhdeh Squares in Yerevan city. The main problem with these cameras is that data is lifestream and it’s not collected for a longer timestamp. Moreover, the companies that own cameras don't have warehouses to keep that much data. The next data source mentioned above is satellite images. There are 3 satellites that collect data from Armenia as well: Landsat-7, Landsat-8, and Sanitel-2. USA launched Landsat-7 on April 15, 1999. At the time it was the most accurately calibrated Earth-observing satellite. Landsat-8 is an American Earth observation satellite launched on 11 February 2013. Those two are the seventh and eighth satellites in the Landsat program. Landsat-7 and Landsat-8 have spatial resolutions of 30 meters. Sentinel-2 is an Earth observation mission from the Copernicus Programme that systematically acquires optical imagery at a high spatial resolution over land and coastal waters. The spatial resolution of Sanitel-2 is from 10 to 60 meters.

The table below represents the number of scenes(images) of Yerevan per satellite mentioned above.

Name	Number of scenes of Yerevan from 09/30/2020 - 09/30/2021	Monthly number of scenes of Yerevan	Coverage in km per scene
Landsat-7	44	3-4	185x180
Landsat-8	35	3-4	183x183
Sanitel-2	132	8-12	290x290

Here it is noticeable that satellites cover a huge area of land which are good for several types of problems described above (Area Coverage, LULC, Agricultural monitoring, etc.), but may not be possible to use in other cases (Damage Monitoring, Surveillance, Fire Detection, etc.)

Conclusion

A huge part of smart city problems can be defined as machine learning and deep learning problems, but the main differences are in data type, size, and structure. Here AI problems are more unique, as domain knowledge and data specialties create new difficulties that are different from classic, general-purpose AI problems.

Smart city problems can’t be solved without accurate data, and remote sensing is one of these data sources that can be most useful. Remote sensing data makes it possible to solve several smart city problems starting from city monitoring with dashboards to AI applications for more sophisticated problems.

However, collection and working with such big data can be an issue. The examples in Yerevan showed that good infrastructure is needed to create the processes of working with such data. Funding from the government or municipality is important to create proper data collection procedures, and warehouses to gather data from UAVs, aerial images, and city cameras. Moreover, it's important to create well-defined procedures and problems to solve with data that is already accessible (like open satellite imageries).

However, the existing datasets can help to work on AI challenges like Area Coverage and land usage prediction, agricultural monitoring, water quality monitoring, etc.

ԼԻԼԻԹ ՅՈԼՅԱՆ – *Համակարգչային տեսլականի կիրառությունը խելացի քաղաքներում՝ օգտագործելով հեռազննման տվյալներ* – Ուրբանիզացիայի մակարդակի աճին զուգընթաց՝ գերբնակեցումը դառնում է քաղաքի և պետական կառավարման, երկրի տնտեսության ամենակարևոր խնդիրներից մեկը: Առաջացած խնդիրները (օդի աղտոտվածությունը, քաղաքի ռեսուրսների պլանավորումը, թափոնների կառավարումը, երթևեկության և տրանսպորտային միջոցների ծանրաբեռնվածությունը, բնակչության առողջությունը) մարտահրավեր են նետում առկա ենթակառուցվածքներին: Խելացի քաղաքի նպատակն է բարելավել հասարակության կենսամակարդակը, ստեղծել ավելի ապահով և կայուն միջավայր, քաղաքային և պետական կառավարման առավել հստակ մեխանիզմներ: Արհեստական բանականության ու համակարգչային տեսլականի կիրառությունը կարող է լուծել խելացի քաղաքի այնպիսի խնդիրներ, որոնք նախկինում անհնար կամ շատ դժվար էր հաղթահարել (վերահսկողություն, տարածքի ծածկույթ, հողօգտագործում և հողի ծածկույթ, վնասների մոնիթորինգ, հրդեհի հայտնաբերում և այլն):

Այս աշխատանքում ներկայացվում է խորը ուսուցման և համակարգչային տեսլականի կիրառությունը խելացի քաղաքների համար՝ օգտագործելով հեռազննման տվյալները: Բացի այդ, ներկայացվում են երկու տեսակի տվյալների աղբյուրներ, որոնք կօգնեն լուծելու խելացի քաղաքի խնդիրները Հայաստանում: Առաջին տեսակը տվյալների հնարավոր աղբյուրներն են, որոնք կարող են հավաքագրվել քաղաքապետարանի ջանքերով, երկրորդը բաց տվյալներ են, որոնք կարելի է օգտագործել ներկայացված խնդիրները լուծելու համար:

Առաջին փուլով հավաքագրվել և հաշվարկվել են բաց հեռազննման տվյալների ծավալները, որոնք կարող են օգտագործվել խորը ուսուցման խնդիրներ լուծելու համար: Ապա նկարագրվել են այն ալգորիթմները, որոնք ավելի են համապատասխանում են տրված տվյալներով խելացի քաղաքի խնդիրների լուծմանը: Հետազոտության արդյունքները ամբողջականացված են աղյուսակ 1-ում:

Բանալի բառեր - *խելացի քաղաք, համակարգչային տեսլական, խորը ուսուցում, հեռահար զոնդավորում, արհեստական ինտելեկտ*

ЛИЛИТ ЙОЛЯН – *Приложения компьютерного зрения для умных городов с использованием данных дистанционного зондирования.* – В условиях стремительно растущего уровня урбанизации перенаселенность стала одной из главных проблем для муниципалитетов, экономики страны и государственного управления. Многие проблемы, связанные с управлением отходами, планированием городских ресурсов, загрязнением воздуха, загруженностью дорог и транспорта, а также вопросами здоровья населения, бросают вызов существующей инфраструктуре. Умный город направлен на улучшение образа жизни людей, создание более устойчивой среды и упрощение управления всеми этими процессами для муниципалитетов и правительств. Применение методов искусственного интеллекта и компьютерного зрения может решить проблемы умного города (наблюдение, охват территории, землепользование и земельный покров, мониторинг повреждений, обнаружение пожаров и т. д.), которые были невозможны или непросты для решения несколько лет назад.

Здесь мы рассматриваем приложения для компьютерного зрения для умных городов с использованием данных дистанционного зондирования. Кроме того, мы представляем 2 типа источников данных для создания наборов данных для решения задач умного города для городов Армении. Первый тип — это потенциальные источники данных, которые могут быть собраны благодаря усилиям муниципалитета, второй тип — это данные из открытых источников, готовые к использованию для нижеприведенных решений.

Во-первых, исторические данные с 3 разных спутников использовались для расчета доступных данных из открытых источников, которые можно использовать для применения алгоритмов глубокого обучения. Далее для каждого типа данных и каждой задачи умного города были найдены и описаны наиболее удобные методы глубокого обучения. Все они были сведены в таблицу 1.

Ключевые слова: *умный город, компьютерное зрение, глубокое обучение, дистанционное зондирование, искусственный интеллект*