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Autonomous Inspections of Utility Networks

Martin Freund

John Mosher

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ABSTRACT

Field inspections of utility network assets are a critical aspect of maintaining the quality and integrity of services provided by a utility. Currently, such inspections are performed largely by human inspectors. Such manual inspections are time-consuming, expensive, potentially dangerous to the inspectors and the surrounding public, subject to human error, disruptive to neighboring communities, and lack the speedy response needed in a disaster scenario. This disclosure describes a machine-based inspection mechanism for utility networks, based on, for example, autonomous or remotely-operated drones with the capability to perform intricate inspections at difficult-to-reach regions and heights. The inspection tasks including, for example, navigation routes, assets and parameters to be inspected, etc. are determined, for example, by a machine learner that has access to real-time and historical data from a variety of relevant sources.

KEYWORDS: Utility network; Autonomous inspection; UAV; Drone

BACKGROUND

Managing a utility network entails regular inspection of physical assets such as vaults, poles, towers, transmitters, etc., which are in the field. Such inspections are important components of deploying, operating, maintaining and expanding the utility network. A majority of such inspections are performed by humans, which poses the following problems.

1. **Time-consuming and expensive**: Inspections to identify root cause of outages often require vehicles and/or helicopters operated by crews of several people. The cost to determine cause of outage is over and above that of actual repair. The logistics and coordination needed to rectify an outage can easily run into tens of hours and thousands of dollars. Additional costs include the cost of lost business and

customer goodwill. Outage repair is often time-sensitive in nature, and every hour of an unrepaired outage caused by slow human response can cost hundreds of thousands of dollars and lead to customer dissatisfaction due to corresponding service outages, e.g., electrical, internet, cell-phone etc. Outages that are repaired manually can also overwhelm available labor resources, slow down new or ongoing deployments, and lead to higher labor costs.

2. **Potentially Dangerous**: The height (fifty to thousands of feet tall) of utility towers and live electrical state of the equipment being inspected are a source of danger to personnel. The fatality rate as well as rate of injuries due to falls or burns is high. Aside from danger to workers conducting the inspections, there is also a risk to the surrounding public.
3. **Prone to incorrect assessments**: Inspections carried out by humans are subject to error due to a variety of reasons, e.g., environmental conditions (windy/hot/cold/icy etc. weather), incentive structure that encourages quick, cursory inspections, etc.
4. **Disruptive impact to customers or residents in the proximity of the inspections**: Helicopters, bucket trucks, crews, roadblocks etc. can have a significant negative impact on the community where inspections take place. The efficiency and/or the required frequency of the inspections can result in repeat visits around homeowners' residences. Utilities located in the rear easement areas require workers to go into residents' backyards. Such access to utility assets, that require crossing of private property, needs coordination between homeowners and utility asset-owner.
5. **Inaccurate utility mapping**: Many utility owners rely on data provided by original vendors. Such data is often based on outdated maps. A utility owner may not have GPS records of their assets, or location data they have may be inaccurate. This inaccuracy can present problems, for example, in locating utilities via rear easement, which could entail investigation through several backyards. Finding the correct backyard requires involvement of multiple homeowners and corresponding

access to their private properties. The situation is exacerbated during outages, where inaccurate location data can cause consequential delays. Utility structure locations change over time, but these changes are often not documented. Poles may have been removed or replaced, for example, due to a storm, or a competitor may have installed utility cables in the location documented as that of the inspected object. In these cases the inspector would be inspecting the wrong utility. If the fact of wrong utility inspection is discovered, it would result in added cost and time for re-inspection.

6. **Poor recovery from disasters**: Manual methods of utility inspections after disasters such as hurricanes, tornados, earthquakes, explosions, fires, etc. can take long. In many cases human lives depend on utilities (e.g. hospital, fire departments, nuclear power facilities, data centers, etc.) being rapidly restored after a disaster. Given the extreme post-disaster urgency, recovery operations incur huge costs due to deployments of helicopters and other aircraft in order to do assessments. Alternately, contractors on the ground have to get to the out-of-service areas by use of truck and other equipment. This involves getting vehicles through debris, which costs precious time and is often unsafe.

Objectives of inspections conducted by a utility provider include the following:

1. **Quality control**: During operation, or prior to acquisition of a utility asset, components of the asset, including structure, poles, transmitters, vaults, towers, etc. are inspected by the utility provider, e.g., to prevent future issues, accidents, and outages.
2. **Identification and resolution of outages**: Accidents, disasters, bad weather, installation or maintenance problems, etc. can cause outages. When an accident or outage occurs, the utility network needs to be inspected to pinpoint the exact location, scale and root cause of the issue so as to determine the solution needed.

3. **Proactive prevention of outages**: Frequent maintenance inspections are important to prevent issues that can escalate into large capital expenses and/or safety concerns. As detailed in safety codes and industry standards, utility owners perform routine inspections of network assets such as poles, wireless transmitters, aerial cables, and antennas/antenna supporting structures. Inspections are also needed after extreme weather and loading conditions, e.g., severe wind and/or ice storms. More frequent inspections have to be considered for structures in coastal, salt water or other corrosive environments, and in areas subject to frequent vandalism, accidents, or extreme weather conditions.
4. **Optimization of asset usage**: Inspections are performed to assess the position of, for example, broadcast transmitters or antenna elements, and to determine if adjustments are warranted in order to optimize for changing usage patterns, improved technology, or network coverage.
5. **Capacity analysis for expansion of installation**: Inspections are performed to ensure that attachments of additional utilities to a structure, such as a building, pole, or telecom tower, are safe, and that the structures are structurally safe and optimized for capacity.
6. **Verification of retrofits or repairs**: Inspections are required after, for example, building over raw land, retrofitting projects, or co-locations, in order to verify that a contractor has completed the work according to the project specifications, codes, and industry standards.

DESCRIPTION

Techniques of this disclosure solve the problems associated with human inspections of a utility's field assets by deploying, for example, autonomous drones to reach assets and perform inspections, and by using, for example, a machine learner to optimize the parameters and paths for drone based inspection. Per techniques of this disclosure, utility inspections are performed as follows:

- Inspection path and parameters are determined using, for example, a machine learner.

- The inspection is physically executed, using, for example, drones or other unmanned vehicles, equipped with sensors and other systems to conduct the inspection. During the inspection, new real-time data is incorporated, which can change inspection paths and parameters.
- Inspection data gathered during inspection is analyzed and assessed using, for example, a machine learner. Analysis and assessments may cause changes to inspection paths and parameters, which in turn inform execution of the inspection.

By automating both the access to the assets (using drones) and the parameters of inspection (using machine learning), per the techniques described herein, the utility service provider accrues numerous advantages:

- **Speed of inspection**: Human involvement and need of travel to field sites is minimized.
- **Cost effectiveness**: No helicopter or vehicle deployment is needed. Since human labor is minimized, inspections become more scalable.
- **Safety**: No aerial deployment, or climbing of hundreds of feet by humans is required.
- **Quality**: Inspections are not compromised by human error or by incentive structures.
- **Reduced customer impact**: Due to the lack of crews and equipment on or near private property and the lack of vehicles, bucket trucks, helicopters, roadblocks, etc., there is reduced customer impact. Assets in backyards, in buildings, on poles, and towers etc. can be inspected with reduced requirement of access permissions. Additionally, techniques are described herein that automatically notify and obtain consent from the appropriate point-of-contact for the respective property owner.
- **Reduced impact of inaccurate utility mapping**: Per techniques of this disclosure, navigation and inspection take place based on real-time map data and information about utility locations and delays due to inaccurate or outdated maps are reduced or eliminated.

- **Faster post-disaster inspections**: As no humans are involved, techniques of this disclosure allow for access to areas compromised by disaster. Such access, per techniques disclosed herein, can be very fast, as the logistical difficulties of activating autonomous drones are lower than deploying a crew of human first responders. In addition, the techniques can access and inspect other infrastructure such as roads, bridges, and buildings in disaster struck areas to determine safe access points and ingress/egress paths for first responders and utility restoration crews.
- **Proactive prevention of outages**: The relative ease of both autonomous drone-based inspections and machine-learning of inspection parameters/navigation routes allows for proactive prevention of outages and effective preparation for natural disasters.

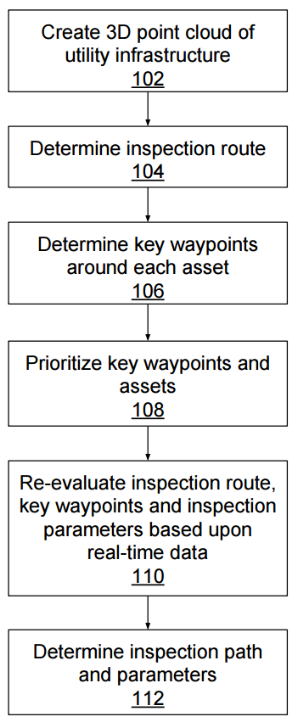

Fig. 1: Determining inspection path and parameters

Fig. 1 shows the process of determining the inspection path and parameters. At 102, a three-dimensional point cloud of utility infrastructure is developed. This point cloud may be based on, for example, aerial scans and historical data arising from proactive and reactive inspections. At 104, an inspection route is autonomously determined. The inspection route may be based on, for example, machine learning, and it may utilize real-time contextual data. Real-time data may be obtained, for example, from sensors or through direct data feeds, and may be indicative of, for example, anomalies or alerts (e.g., disasters, accidents, outages etc.). Real-time data may also originate from reports generated by crew operating in the field, utility application data from within the utility industry including competitors and third parties, data generated by utility equipment etc. At 106, key waypoints around each asset are determined. The determination of key waypoints is based on, for example, machine learning, and may utilize real-time contextual data. At 108, assets to be inspected and waypoints around each asset are prioritized. This prioritization is done dynamically, and may be based on, for example, an evolving set of historical inspection data as well as contextual real-time data. At 110, the inspection route, key waypoints, inspection list, parameters, etc. are re-evaluated, modified and re-optimized if necessary, based upon the latest real-time data and alerts, and the relative risk or importance of each alert or piece of real-time data.

Using the point cloud, the inspection route, the key waypoints and prioritizations thereof, a machine learner determines the inspection path and parameters (112). In developing the route, deployment pattern, key waypoints, inspection list, parameters, etc., a machine learner considers with differing weightages several data points, including data from maps, geographical data, weather data, seismic data, atmospheric data, flood data, historical data regarding maintenance and frequency of inspection of individual assets, etc. Such data may be used, for example, to deduce and predict patterns. The relative risk or importance of each datum determines the weight assigned to that datum. The risk or importance of a datum may be based, for example, on the numbers and severity of customers affected, human safety, operational costs, reputational impact, etc. Patterns of failure, as determined, for example, by a machine learner, may be used to determine the likelihood of occurrence of an outage. For example, historical trends, weather data, NOAA data on weather indices such as barometric pressure, temperature, wind speeds etc., USGS data on earthquakes, tremors, predictable tsunamis, etc. are used to predict areas that are prone to outages due to accidents, severe weather conditions and disasters. The machine learner determines intensity of impact, for example, the effect on utility systems when a series of small tremors take place, or the effect on a utility system when a Category 5 hurricane hits an area.

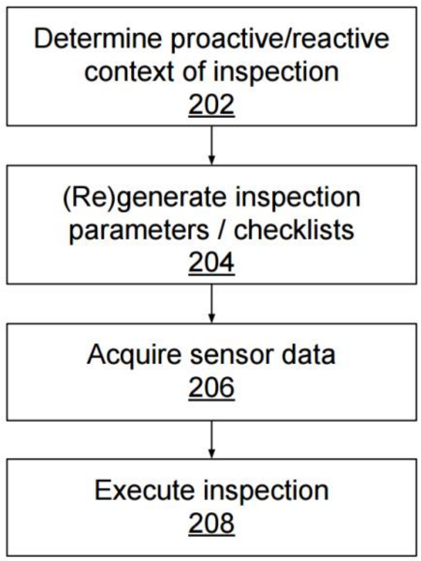

Fig. 2: Executing an inspection

Fig. 2 illustrates the process of executing the inspection. The reactive or proactive context of the inspection is determined (202). These contexts may be re-evaluated during the course of the inspection. Assets are inspected based on the proactive or reactive context of the inspection. The inspection parameters and checklists may be dynamically (re-)generated based on the analyzed historical and real-time data (204). Sensors provide data (206) that facilitate the execution of the inspection (208). Inspections utilize a combination of a number of sensors to inspect, calculate routes, and navigate. For example, an inspection may use laser/lidar, radio-frequency (RF) heat maps, ultrasound imagery, video, infrared sensors, holographic sensors, RF sensors, electrochemical sensors, humidity sensors, litmus-type thermochromic or solvatochromic sensors, gyroscopes etc.

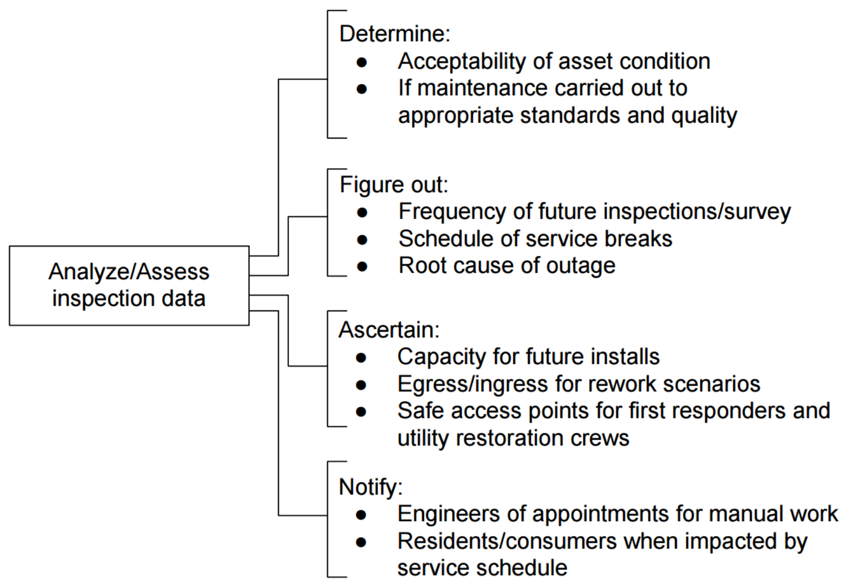

Fig. 3: Analyzing inspection data

Fig. 3 shows the process of analyzing and assessing inspection data. Such analysis and assessments may be carried out autonomously, for example, by a machine learner, and may inform the future path, waypoints, inspection parameters etc. of the drone that is carrying out the inspections. Analysis and assessments are made towards a number of objectives, including the following.

- Determine, based for example on predefined parameters, the acceptability of an asset, including: quality and integrity of work or retrofit done on the asset, conformance to industry standards and quality norms, etc.
- Figure the root cause of an outage, accident or disaster, including:
    - proactive measures to prevent future outages and ensure public safety;
    - schedule of service breaks, for example, to provide software/hardware patches or adjust or align antennas or other equipment;
    - frequency of, and next date for, future inspections or survey;
    - map patterns of changing environment or context around an asset, and how that may affect the likelihood or frequency of future outages, etc.

- Ascertain capacity for future installs, including:
    - options to optimize current utility installations, for example, optimizations to improve transmitter coverage based on latest usage patterns;
    - egress/ingress for rework, retrofit, or optimization projects, including: effective and safe entry and exit routes for maintenance crews with minimal impact on surrounding public, environment and property;
    - safe access points for first responders and utility restoration crews.
- Notify stakeholders of upcoming service appointments, including:
    - notices sent to remote engineers about manual work needed based upon autonomous inspections;
    - notices sent to customers and property owners to obtain consent for future scheduled inspections.

CONCLUSION

This disclosure describes a drone-based autonomous mechanism for field inspection of utility networks. Parameters of the autonomous inspections, e.g., navigation routes, assets to be inspected, key waypoints, etc. are determined by a machine learner based upon real-time and historical data. Real-time and historical data originate from a variety of sources, including sensors, disaster-warning authorities, industry data etc. Autonomous inspections are informed by ongoing analysis and assessment performed by the machine learner. Such assessments may modify the inspection in a real-time fashion. In this manner, techniques of this disclosure solve the problems with human-based inspections, such as expense, time, danger, human error, impact to surrounding communities, outdated maps, response time for disasters, etc.