Internet of Things as a Tool for Equitable Flooding Protection

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree Bachelor of Science, School of Engineering

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Spring 2023

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Intro

Hurricane Katrina, regarded as one of the most catastrophic climate disasters in recent American history, resulted in the deaths of more than 970 people in Lousiana, 40% of them directly related to flooding. 51% of the lives lost were Black Americans (Brunkard et. al, 2008). The American public conscience was inundated with images and news clips of people stranded on rooftops and on top of cars, unable to receive help. Unfortunately, Katrina was certainly not the last flooding event of that scale. Hurricanes Sandy and Harvey also come to mind when thinking of severe flood events of the last decade where the costs were $70 billion (Rott, 2021) and $125 billion (TDEM, 2017), respectively. Between 1985 and 2015, the average annual cost in damages from flooding was $8.2 billion in the United States, with 105 casualties per year (FEMA, 2022), making them the “most common and costliest natural hazards in the United States in terms of lives and property losses” (Qiang, 2019). And while many of us will not experience a Katrina or Harvey-sized flood, if you live in the United States, chances are that the place you live has seen a flood of some sort during your lifetime. In fact, FEMA estimates that 99% of US counties have been impacted by a flooding event between 1996 and 2019. Needless to say, flooding is a wide-reaching climate issue with the potential for disastrous consequences.

Catastrophic flooding events have exposed the inability of flood infrastructure to prevent said consequences and support rebuilding in the aftermath, especially among marginalized communities. There are many examples of racial and socioeconomic disparities related to flooding events. Compared to white households, African American households were 1.5 times more likely to have their homes flooded and Hispanic households were 1.3 times more likely to have their homes flooded(Cutter, 2006). Low-income communities in both rural and urban settings face a higher risk of flooding (Center for Social Solutions, 2021).

What if there were a way for low income, majority POC communities to receive valuable warning data ahead of flooding events so that they could adequately protect their neighborhoods and evacuate safely and more reliably? That's where Internet of Things (IoT) makes its entrance. IoT in the context of this paper refers to technologies that use live sensor data to relay information about the state of environmental systems without the need for human input.

Internet of things technologies use a protocol called Low Power Wide Area Networking (LPWAN) to transmit live data through a gateway which can then be collected and analyzed. In the context of flooding, some of the hydrological parameters measured by IoT devices include soil moisture as well as water level and flow rates in streams and stormdrains. These data could then be used to predict flood events and be integrated into an effective emergency preparation and response plan.

Current flood infrastructure is marred by its one-size-fits all nature and environmental and economic policies that ignore the social positioning of marginalized communities, creating an inequality gap which manifests in the aftermath of floods. IoT provides a remedy for these inequalities because of its affordability and accessibility, its ease of implementation, and its versatility. In this paper I conduct a literature review of some of the causes of the inequality due to flood infrastructure today, using Star's *Ethnography of Infrastructure* (1999) as a lens. I then use the same framework to analyze case studies of current IoT environmental monitoring systems to determine how they achieve environmental justice, and offer IoT for flooding as a solution to environmental inequality.

Literature Review

Star's ethnography of infrastructure provides a useful framework for evaluating the inequities in current flood infrastructure. Infrastructure can be seen as a complex socio-technical system that involves multiple actors, institutions, and material factors, all of which have different interests, values, and power relations that shape the design and use of the system (Star, 1999). Applying this framework to flood infrastructure allows us to consider how it is shaped by and shapes the social and environmental contexts in which it is used, and to identify gaps that may be the cause of inequality within the system. I will be using the concept of “reach” as described by Star to evaluate existing flood infrastructure and the way it perpetuates inequality. The concept of "reach" or "scope" refers to the extent to which an infrastructure system can accommodate and respond to the diverse needs, interests, and expectations of its users and stakeholders (Star, 1999). Reach can be seen as a measure of the flexibility and adaptability of an infrastructure system, as well as its ability to evolve and change over time.

By reviewing various sources I have first identified the determination of risk to be a shortcoming of reach in an integral part of flood infrastructure. A one-size-fits-all format of flood risk assessment obscures the elevated risks faced by marginalized communities. In a 2015 case study showing a logistic regression analysis of flood risk in Miami, Montgomery and Chakraborty showed that the controlled variables included in a flood risk model could dramatically change the outcomes. Models which did not control for water-based amenities (seasonal beach homes, access to beach sites) showed that neighborhoods with high percentages of Hispanic and non-Hispanic Black residents have “decreased odds of coastal flooding” (p.8). When controlling for such amenities, the results indicated significantly increased flood risk (p.8). Similar results were found when treating inland flooding and coastal flooding separately. Another commonly employed method used for the determination of flood risk is the “100 year floodplain" or "100 year flood zone" laid out by FEMA. It denotes the areas which it says have a 1% chance of flooding each year. In a study of the greater Houston area in the aftermath of Hurricane Harvey, it was found that there was limited evidence of racial inequalities within the 100 year floodzone. However, the racial inequalities which were made obvious by Harvey led to research showing that these effects were "driven by impacts that occurred outside of 100-year floodplains" (Smiley, 2020, p.1). In roughly thirty years preceding Harvey, 47% of all flood damage claims surrounding Harris county came from areas outside of the 100 year floodplain (Highfield et al., 2013, p.189). We can see that FEMA neglected to update its assessment despite the data indicating that it was not sufficient. The failure of FEMA to be more comprehensive in their indications of risk– and to consider an assessment of social vulnerability and resilience– led to decisions that ignored the unique social positioning of different communities within the Houston area, and which placed the inequalities present in the city on full display. According to Bulti et al., "Community flood resilience is the ability of a community -and all of its socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of flood events, to adapt to change, and to transform systems that affect the current and future adaptive capacity" (Bulti et al., 2019, p.4) We can see that in order for flood risk assessments to successfully operate with effective reach, they must adopt a dynamic approach to not only the way that they consider demographics, but in the way that social and environmental conditions evolve over time. Furthermore, this research has showed that neglecting assessments of community resilience, and relying solely on environmental data are a way that current flood risk assessments have failed to effectively protect marginalized communities. The ethnographic approach emphasizes the importance of understanding these social dynamics and identifying ways to address them in the design and implementation of flood infrastructure.

Given that the ethnography of infrastructure encourages us to view infrastructure as a complex system that transcends physical constructions we should also consider the way in which environmental and economic policies have hampered the ability of flood infrastructure as a whole to have an effective reach, and have continued to create an inequality gap. Historical redlining practices– in which communities with large proportions of low-income residents and or people of color were labelled by banks and city governments as "high-risk" for investors, as well as denying access to mortgage loans and other services to people living in those communities– has manifested itself today in the inequalities faced by marginalized groups during flood events. Redlining led to marginalized populations being concentrated in flood-prone areas, and left them with little access to effective flood infrastructure. Historically redlined communities face an 8.4% risk of flooding, compared to a 6.9% risk in non-redlined zones across the United States, coinciding with the continual disinvestment in these communities (Cannon and Capps, 2021). In Atlanta and Portland, installations of green infrastructure were largely concentrated in certain areas, which overlapped with areas of high income, white residents (Pallathadka et al., 2022). The Hazard Mitigation Grant Program started by FEMA in the 1980's was intended to allow Homeowners to sell their flood-prone properties to local governments and have the sales financially assisted by the federal government. Between 1987 and 2017, Elliot et al. (2020) found that the majority of financial assistance was targeted in white counties, and white neighborhoods within those counties (pg.12). The National Flood Insurance Program (NFIP), which was established in 1968, provides federal insurance for properties located in flood-prone areas. However, the program has been criticized for disproportionately benefiting higher-income property owners, who are more likely to be able to afford flood insurance and to own property in low-risk areas. In contrast, lower-income property owners are often unable to purchase flood insurance and are left with few options for rebuilding after a flood (Elliot & Pais, 2006). Georgia is the only US state which requires that landlords inform renters of flood risk in extreme cases, while the law in other states only requires that flood risk be disclosed to potential buyers (Center for Social Solutions, 2021). Renters of lower socioeconomic status are most harmed by this policy. All of these government interventions show that flood infrastructure through environmental and economic policy has been designed and implemented in ways that prioritize the protection of affluent and white communities, while neglecting the needs of marginalized communities. This can lead to significant inequities in terms of who is protected from flooding and who is left vulnerable to its impacts because poor communities and communities of color lack access to economic resources and social capital which would allow them to develop and maintain effective flood infrastructure, and recover from the results of a disastrous flood event.

Methods

In this paper I seek to understand how Internet of Things can be a part of the solution to the inequities I have identified in the previous sections. To achieve this, my research will consist of reviewing case studies– from journal articles as well as from websites of organizations creating environmental IoT projects– of IotT being implemented in environmental monitoring capacities. These case studies have shown that IoT can be a successful way to predict climate disasters by relaying data about a wide variety of environmental parameters, but research linking those endeavours to any sort of social equality initiatives has yet to be conducted. I will also be drawing on my own experiences working in a capstone project that has installed and implemented a rudimentary IoT infrastructure to measure flood related parameters in Charlottesville, Virginia, to discuss the unique challenges and advantages of working with IoT. Through my research I aim to determine how these undertakings have been successful in contributing to a holistic, systems approach to flood protection, and equality. Once again, I will be using Susan Leigh Star's *Ethnography of Infrastructure* to analyze these case studies. Star introduces several key concepts and characteristics of infrastructure that will be useful for evaluating how the IoT system of technology– which is currently in the making– is both becoming a part of existing infrastructures, and distinguishing itself as a new form of infrastructure that could serve to lessen the gap in inequality following floods. These will be explained in further detail in the analysis portion.

Analysis

Internet of Things provides an affordable means of environmental modeling, making it an ideal candidate for addressing the disproportionate damage of flood events in marginalized communities. IoT sensors are generally inexpensive while being able to transmit considerable amounts of data about a variety of parameters. The United States Department of Homeland Security estimates the average cost of IoT flood sensors (roughly $1000 based on figures from 2018) to be 5% of the cost of standard permanent flood sensors (p.1). At just a fraction of the price of previous flood detection technology, IoT is an obvious choice for communities who may have not otherwise benefitted from the prediction capabilities that flood detection sensors can offer. Da Silva Junior et al. describe a "low-cost, modular and scalable IoT … where sensor data can be accessed through a web interface or smartphone, without the need for existing infrastructure at the site where the IOTFlood solution was installed using affordable hardware" (2021, p.1). The authors of that work found that ultra sound and pressure sensors are incredibly effective, and were able to create an effective system that performed in the lab as well as in the field for a total equipment cost of around $300 (p.12). In my groups capstone project, which included the implementation of new sensors we were able to install new sensors in the field for a similar, low cost and expand upon a previous group's system installations. These show the power of IoT as a low-cost system that can be useful for tracking flooding, and delivering valuable information to communities. Star's method asks us to view infrastructure as a "fundamentally relative concept" (Star, 1999, p. 380). So, we should consider the following question: who is being served, and who is fighting to be included? As previously mentioned, the ripple effects of historical redlining policies are still felt in poor, majority POC communities through a lack of investment and funding into flood protection resources. It is this lack of resources that IoT is able to circumvent in order to provide said communities with the ability to track and respond to severe flood events. The low cost of IoT implementation and maintenance makes it possible to imagine installations on a large scale, with nearly every community that might want it being able to roll out enough sensors to create a relatively sophisticated, comprehensive system.

A trademark of IoT that makes it so beneficial for use in communities where existing infrastructure is limited and or outdated is its ease of installation. The wireless nature of IoT sensor/gateway systems eliminates the need for complex setup processes. This makes it possible for IoT sensors to be placed in areas where traditional wired sensors may not be able to reach. In my experience working with IoT installation, sensors can be mounted on bridges, in soil, storm drains, and on telephone polls. Often, they require only an adhesive, a zip tie, or a shovel, and are the size of a handheld radio set. One of the characteristics identified by Star is that infrastructure is “built on an installed base” (p.382), and although IoT is not necessarily reliant on existing infrastructure, I would argue that this is one of the ways that IoT both builds upon current infrastructure, and sets itself apart as a new, adaptable, and versatile form of infrastructure. Star also points out that infrastructures are fixed in modular increments, and not all at once. One way which this is true for IoT is that these devices can be swapped in and or added to the system, while not requiring an entire upheaval of the existing infrastructure, allowing it to be managed effectively.

The open data structure, and the comprehensive analytical capabilities of IoT make it a versatile way for communities to create their own system to support emergency decision making using open-source software, and make the information publicly available. The “Breathe London” project uses IoT sensors to create an interactive map detailing levels of particulate matter, with a priority of creating a “citizen and community-led” air quality monitoring system in under-served communities in London (Kelly and Barratt, 202). A similar model for IoT for flooding could also be adopted in which crucial geospatial, demographic, and risk and resilence data are synthesized into a comprehensive model whose trends, alerts, and warnings can be accessed by the public. Since access to internet is all that would be necessary to reach these data, this would make IoT for flooding an incredibly accessible way for residents of underserved communities to stay up to date with their own flood risk. As was established earlier in the paper, flood risk disclosure policies are one of the gaps left by flood infrastructure which primarily affect low income populations. Providing a way for residents of these communities to take situations into their own hand through access to information about their own risk level positions them closer to resources such as insurance, and emergency aid, as well as assisting them in advocating for policies that would improve their surrounding infrastructure.

IoT infrastructure involves a range of material and environmental factors that affect its sustainability. The ethnographic approach encourages us to consider these factors as integral parts of the IoT infrastructure and to explore ways to minimize their negative impacts. The primary concern is that as the IoT market continues to grow towards a projected $650 billion in 2026 (Belokrylov, 2022), there is a possibility of unsustainable consumption of power and manufacturing materials due to the sheer scale (Nizetic et. al, 2020). However, because IoT devices are already generally more compact, they generally already use less material and energy than non IoT sensors of the same capacity. The internet-based communications property also eliminates the need for extensive and sometimes invasive wiring. These factors are also important to consider when evaluating IoT as a sustainable system for environmental monitoring.

Conclusion

The basis for flood infrastructure thus far has been built on policies and practices that negatively affect historically marginalized communities. IoT's affordability and accessibility, its ease of implementation, as well as its open data structure make it a strong candidate to upgrade some of the degraded infrastructure in place in underserved communities. IoT for flooding is a complex socio-technical tool that involves multiple actors and institutions, including designers, engineers, manufacturers, regulators, and users, who have different interests, values, and power relations that shape the design and use of the system. We should aim to understand the strengths and limitations of IoT for flooding as a system, as well as the responsibilities of those who can mold it and implement it in communities that need it. IoT for environmental monitoring– and specifically for flooding– is embedded in broader social and political contexts that shape its goals, priorities, and implications. For example, the use of IoT data to inform environmental policy decisions may have significant consequences for different communities, including historically marginalized communities, who may be disproportionately affected by environmental degradation. Star’s approach emphasizes the importance of engaging with these broader social and political contexts and ensuring that the IoT for flooding is designed and used in ways that promote social and environmental justice. Future research about the social impact of Iot for flooding should consider the expansion of the IoT market, and how the arrival of new products can create a more sustainable version of current systems, and how this may change the associated economic costs to the communities that wish to use them.

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