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Context-Aware Systems: A More Appropriate Response System to Hurricanes and Other Natural Disasters

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Abstract

A context-aware system may be defined as a system that can understand the context of a given situation and either share this context with other systems for their response or respond by itself. Context has many definitions such as additional information that further describes a given situation. However, the definition of context is very contentious – what is considered context in one system may be considered unimportant in another.

In this paper, we focus on the ability of context-aware systems to respond to external events, in particular incoming hurricanes, in an appropriate, authorised and regular manner. Hurricanes are often problematic in that they may be difficult to predict, in terms of direction and intensity, and require immediate and appropriate responses. We look at how this system will respond to an authorised set of stimuli using a pre-defined sequence and set of behavioural rules. The response produced by the system will be appropriate depending on the context of the stimuli received.

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Keywords: context-aware; hurricane; natural disaster; disaster management

1. Introduction

A context-aware system, is defined by [10], as "a web service that can understand situational context and can share that context with other services". However, what is considered contextual information in one system may be disregarded in another.

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One of the most critical roles suited for complex adaptable systems are natural disasters. An example, hurricanes may be difficult to predict, especially with respect to their intensity and direction, but they require timely and appropriate responses as needed in order to minimise damage. [6]

Examples of where human systems failed but where complex adaptable systems may have had an opportunity to play a bigger role are Hurricanes Katrina and Irene. The disaster and poor and timeous responses to disasters can be seen in the aftermath of Hurricane Katrina, which devastated New Orleans, in 2005 and in Hurricane Irene in 2011. Certain operations within a small Caribbean country are used as a case example of how context-aware systems can respond more appropriately to disaster management when human procedures are not carried out or fail.

2. Literature Review

Traditionally, systems were built using well-designed components according to a precise blueprint in order to behave in a predictable way. Using the basis of bacteria organizations that create new knowledge according to their genetic codes, complex adaptable system consist of required codes and principles which organize themselves according to externally received simulation.

The result of these type of system is an adaptable system that is able to accomplish many tasks and to change according to received stimuli. [3]

These stimuli are often uncertain. Truong considers contextual information, such as stimuli, as supplementary data that may be utilised to improve the behaviour of a system. [19] The contexts consists of variables such as random variables that are uncertain or undefined. [12] McManus mentions that the world is growing more complex with more uncertainty in many situations. Information systems must have the flexibility to evaluate these uncertain contexts and react appropriately. [12]

There are many approaches to managing uncertain stimuli and articulating their responses. Madey looks at detecting and managing an anomaly in stimuli through the use of integrated web services, call pattern usage, and statistical packages in order to first detect an anomaly and then use agent-based simulations to try to find an explanation for the event. The data source that indicated an anomaly may be queried for further information, where possible. The event is classified and its evolution predicted, with appropriate alerts sent out. [9] However, the security of these alert notifications are not examined. [14]

One case of uncertainty within context is the weather. The US National Oceanic and Atmospheric Administration sends out regular forecasts and warnings of inclement weather, in order to protect life and property. [21] Although the Caribbean nation, in this study, has its own weather system, most of the nation's populace relies on the US system due to its close proximity (30 miles) to the US and, hence, its relevance to the nation's own weather. In addition, the nation's system has personnel issues which make it unreliable. [13]

Traditionally, hurricanes were predicted using simple warning signs that occur 36 to 24 hours before the hurricane hits landfall. An example, thirty-six hours before a hurricane hits land, the pressure begins to fall, a slight wind occurs, and ocean waves increase to 10 to 15 feet. White cirrus clouds are present. Twenty-four hours before the hurricane hits landfall, the wind speed has increased to approximately 35 mph, skies are overcast, and seas have rough, choppy waves. [7] Using simple sensor technology (sea buoys that infer height estimates using a truncated wave energy spectra) for wave height, a barometer to measure air pressure, and photo diodes to determine the degree of overcast of the sky, it was possible to determine these hurricane warning signs electronically. [15] However, since the 1950s, with the use of satellite technology, improved weather radar, and various hurricane forecast models, hurricane forecast advisories may be 10 to 12 days in advance of landfall. One of these models, the Advanced Circulation Coastal Ocean and Storm Surge (ADCIRC), was used to forecast Hurricane Gustav in 2008 in terms of predicted vs later measured actual intensity, tracking, water levels, wind speeds, and landfall times. [22] Another model, the ECMWF forecasting simulation, accurately predicted Hurricane Sandy's landfall in 2012 in the US with a 7 day forecast. Using sea surface temperatures, this ECMWF model was particularly useful in pre-determining the hurricane's wind speeds and precipitation levels. [23] However, these models are not entirely accurate as hurricanes may shift in direction and intensity with landfall significantly less than a 7 day forecast. [24; 13]

Several context-aware adaptable system were built to handle natural disasters. Truong outlines a toolkit of middleware that allows collaborative communication and co-operation amongst disaster relief workers on the ground. [20] However, this toolkit does not address the issue of strategic-level disaster management and in ensuring that all areas of disaster management have been addressed. This lack of comprehensive coverage was problematic in the example of a Caribbean country during Hurricane Irene and this lack of comprehensive coverage forms the focus of this paper. [13]

In terms of management of a disaster by government, Sobel attributes the poor government responses to disaster relief in the immediate aftermath of Hurricane Katrina to government inter-departmental infighting and over-cautiousness. Both an Amtrak train and several inter-city buses, which could have evacuated many people of New Orleans from the disaster, left empty because a government department, FEMA, did not respond to their request to board passengers. [17] The Caribbean airline's response was due to panic and non-ensurance that all matters were taken care of. The airline let most of its employees leave at noon the previous day (the hurricane hit the next morning) in order to prepare their homes for the upcoming hurricane. While this action may be deemed to be humanitarian, the airline first did not ensure that all needed procedures, to be done in the event of a hurricane, were carried out first. This action had repercussions both during and after the hurricane. Flights, originally scheduled to fly out when the hurricane hit, were officially still scheduled and any affected passengers could not rebook their flights, without penalty. Furthermore, these passengers had to wait in airports for up to two days because the airline was unsure of the number of displaced passengers and what flights to put them on. This delay was exacerbated because a flight, scheduled to fly out stranded passengers during the night, was cancelled at the last minute because "the destination airport landing lines were not put on". This cancellation highlights a failing of both management and the ground crew of the destination airport to ensure that all proper procedures are carried out in a disaster. [13]

To highlight the role of individual initiative, Sobel cites the "tale of two sheriffs". Sheriffs Evans and Randle both were prepared to bring badly-needed assistance to the hurricane-struck victims of Katrina. However, Sheriff Randle obeyed FEMA orders to await for its approval before acting while Sheriff Evans ignored the orders of both FEMA and his state governor and went anyways. His relief was one of the few efforts to reach the city and provided urgently-required relief to its inhabitants. [17] However, one issue in this "tale of two sheriffs" is that while their initiatives were welcome, there was a very real possibility that each individual initiative could work at cross-purposes to the other. An example, both sheriffs could bring truckloads of bottled water but not bring any food. This issue brings into the forefront the argument that while individual relief initiatives are often welcome, they need to be coordinated at a higher strategic level.

In order to better define the components and mechanisms of a complex adaptable system. Ross highlights change in terms of change agent, effect, mechanism, and resulting possible paths. A change agent may be a natural event or impetus from software. Ross defines the effect of the system to the change agent, if the agent is internal to the system, as adaptable and as flexible if the change agent is external. The change effect is governed by the change parameters as to the degree in which it is allowed to change. These change parameters may be technical parameters or cost parameters set by stakeholders. The set of change parameters results in a "space of design" or possible outcome actions. For the parameters, each design is evaluated in regards to a set of attributes, which are then are categorised into groups. [16] Although Ross has pre-determined variability of parameter values and categorisation into groups, this approach does not take into account combinations of different parameters which might result in the same action being taken.

3. Approach

Our approach consists of aggregating multiple factors, derived from sensory data from different sources, and based on their aggregate condition combination (the context), the system will perform a series of actions and sub-actions that correspond to this context combination. Each action and sub-action are requested to be performed by external actors and these requests remain outstanding until confirmation of the completion of their action is received. In this manner, it can be ensured that the full set of actions, as defined by a given context, be carried out.

Context may be composed of multiple factors and may be denoted by C_{ijk}, a contextual tuple, where $_{I,\ j,\ k}$ are specific contextual factors. An example$_{,\ I}$ may represent the wind speed, $_j$ the amount of rainfall, and $_k$ may represent the wave height. Depending on the particular combination and values of the contextual factors, one or more actions may be performed. An example, a wind speed up to 25 knots would not prevent an airplane from taking off but this windspeed, in combination with an above-normal amount of precipitation, would result in the airline flight being cancelled due to the danger of take-off. This combination of factors (context) are found in FAA-approved formulas and tables which airlines consult, after determining current conditions, in arriving at a decision of whether or not to allow a flight to take off.[18] For each contextual tuple, there are a number of pre-determined steps that should be followed. In the case of a hurricane, Miami Airport sets out a clear policy and steps to be followed under various conditions. [8] These steps are denoted as Actions $\{A_0..A_N\}$.Even one of these actions involves a set of sub-actions $\{S_{A0}..S_{AN}\}$. One of these sub-actions might include cancelling flights immediately before, during, and after the hurricane ("hurricane window"). Each sub-action, S_{ai} involves several sub-steps. An example, the sub-action of cancelling a select flight includes removing the flight from the schedule on the airline's web server, notifying passengers scheduled on that flight by their preferred contact method (such as email or SMS), and supplying the number of passengers scheduled for that flight to the airline's flight scheduling system for allocation for future flights. Although not every passenger scheduled for a just-cancelled flight may choose a later flight, this sub-step alleviates some of the confusion and total unpreparedness that greeted passengers stuck at both airport endpoints due to cancelled flights due to Hurricane Irene. [13] The scheduling system can compare the number of displaced passengers to the number of empty seats in immediately successive flights. If the number of displaced passengers greatly exceeds the number of empty seats, further action may be taken such as scheduling of special flights.

A system must be able evolve to meet changing conditions. If hurricane conditions persist as indicated by the sensory data, the system must continue with its "hurricane lockdown" behaviour – cancelling affected flights, informing affected passengers, and supplying the number of passengers scheduled for the affected flights to the airline's flight scheduling system for allocation for future flights. If the hurricane passed, as indicated by the sensory data and confirmed by the FAA, the flight scheduling system is notified and hurricane-affected passengers are allocated spare seats in upcoming flights. If sensory data indicate a slight improvement of conditions (non-flyable weather but decreased wind and rain) and a Web call to US National Oceanic and Atmospheric Administration indicates that the hurricane has passed (no future hurricane bands approaching which may pose danger to ground crew), the "hurricane lockdown" behaviour in regards to flights continues but coordination of ground crews in the relief effort through SMS/emails begins.

Example System

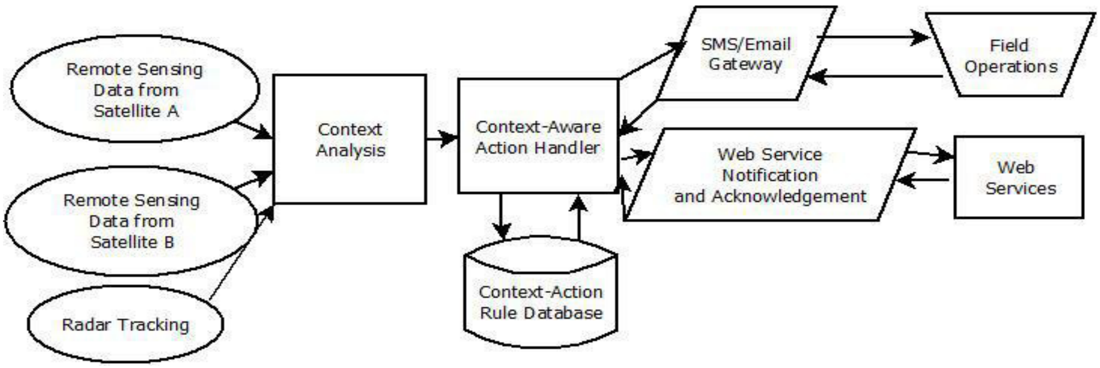

Fig 1. Architecture of Context-Aware Management System

In Fig. 1, the architecture of the context-aware management system is illustrated. Various sensory data (originating from satellites or radar and which could be for wave height, windspeed, et al) feed information to a context analyser. The context analyser then passes the aggregated information from the various sensory data to the context-aware action handler. This handler interacts with the database to find the set of actions most closely related to the given aggregate context. Once retrieved, these actions are implemented. To implement, in terms of informing another web service, the Web Service Notification and Acknowledgment module sends, via secure XML, a request for action to the appropriate Web service. The Web service, in return, performs the action and sends an acknowledgement of completion to the Web Service Notification and Acknowledgement module. This module passes the acknowledgement message to the Context-Aware Action Handler which would then update the database that this action(s) have been performed. This architecture assumes that the client Web service is configured to handle these type of requests by the Context-Aware Handler.

To manage non-web services, such as teams in the field, the action handler notifies the field operators of the action(s) to be taken through the appropriate communication channels using the SMS/Email gateway

The system's SMS/Email gateway uses playSMS Webservices API to send and receive SMS to field operators and a simple mail server to manage emails. The outgoing SMS would inform the field operator of the action(s) to be performed and the incoming SMS from the field operator(s) would inform the Context-Aware Action Handler, via the SMS/Email gateway, that the task(s) have been completed. The Context-Aware Action Handler would then update the database that this action(s) have been performed.

Table 1: Selected Samples of Conditions, Calculation of Aggregate Conditions, and Partial Response

Visibility	Temp	Windspeed	Wave Height	Air Pressure	Ice/Humidity	Calculation	Response
3SM	20C	-	-	-	-	Reduced visibility	Landing lights
-	-	25 knots	-	-	Dry	Ok	Go-Fly
-	-	25 knots	-	-	High Humidity	Dangerous	No-Fly
-	<0C	5 knots	-	-	Ice	Dangerous	No-Fly
-	-	2 knots	10 ft	dropping	-	Approaching Hurricane	Cancel flights during hurricane; prepare

Table 1 indicates a few samples of the status of various conditions along with the calculation of their combinational value and their response. In case of factors that might lead to an ambiguous response, the combination is escalated to a human expert for their response determination. A Go-Fly response indicates flights continue as normal while no-fly indicates that determined flights will be cancelled, their affected passengers notified, and plan for these displaced passengers on future flights. When fed in sample data of 3SM for general visibility combined with a temperature/dew point of 20, the system signaled a red flag for reduced visibility. This flag resulted in warnings sent to the airline via email for their crews to use special instrumentation and in SMSs sent to the airport ground crew to turn on landing lights to increase visibility. [4] When fed in dry conditions and a cross-wind of 25 knots on landing, the system indicated a go-fly indication. However, when fed in a cross-wind of 5 knots but ice-covered runways, the system indicated a no-fly condition. [18] Even with cross-winds of 25 knots, the conclusion of whether to fly or not may be dependent on other factors, such as low or high humidity. When fed in sample data of wave heights at 10 ft., dropping pressure, and a slight wind, the system confirmed its readings and confirmed its possible conclusion via a Web service call to US National Oceanic and Atmospheric Administration or similar agency. In the case of sensor malfunction in the other cases, manual sensors and visible observation could be used to confirm conditions. However, a confirmation from such an agency would both prevent false positives where the system would react in “hurricane-shutdown” mode in the case of sensor malfunction and would address the problem of false negatives where calms in-between hurricane bands could indicate misleading “hurricane over” conditions, as per sensory data, until the next hurricane band approached. Once confirmed, the airline sent a message to its flight scheduling system to cancel flights that were 30 hours in advance and plan for displaced passenger on future flights, inform the affected passengers via its email/SMS gateway, and contact the nearest airport, which was outside the hurricane proposed path, to allocate space for its aircraft to be stored. The storage of aircraft outside the hurricane’s path prevents damage to aircraft, which might occur even if they are in hangars, and enables them to be able to fly once the hurricane passing. But notifying the closest airport, these planes can be allocated space and given the flight cancellation to hurricane landing window, these planes can be flied out safely.

5. Conclusion

This paper proposes a system that is able to calculate the impact of multiple factors derived from remote sensory data. This calculated impact would result in a pre-determined comprehensive set of action(s) that would be followed. This set of actions would ensure that all steps would be followed rather than relying on human-based intervention which, in the case of several incidences of hurricanes, has been demonstrated to be woefully inadequate.

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