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ENABLING A WILDLIFE-ROADWAY COLLISION WARNING AND MITIGATION SYSTEM USING WIRELESS SENSOR NETWORKING TECHNOLOGIES

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Project Title

Enabling a Wildlife-Roadway Collision Warning and Mitigation System using Wireless Sensor Networking Technologies

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Summary

In this project, we have tested different platforms, approaches and techniques to develop a prototype network for a wildlife-roadway collision warning and mitigation system. The system utilizes wireless sensor networking (WSN) technologies and emphasizes on energy efficiency, low cost and easy deployment and maintenance. It is through this research that we conclude wireless sensor networking technology has great a potential for future applications in wildlife-vehicle collision avoidance and environment monitoring, where network nodes co-operate to achieve network functionalities. Highly qualified personnel (HQP) training goal has been successfully achieved through the project work. The most challenging task, however, lies in the effective sensing techniques for large scale environment and resource constrained networks, which need further future investigation.

Project Work Description

We have conducted a thorough literature survey of existing wildlife-vehicle collision prevention technologies and systems. A comparison of the effectiveness and cost of existing methods is studied. The survey study leads us to consider a multi-tier collaborative sensing and decision making architecture using wireless sensor network technology. The warning system is designed to be comprised of three levels of wildlife crossing detection subsystems. Nodes of different levels work together to cooperatively make crossing decisions. Because crossing decision event possesses local importance and is time critical, we considered the alarm signals in the lab settings using visible lights (LED/LCD) and sound (buzzer) as soon as such crossings are detected. To extend the scope of the network, real-time data can be sent through cellular data networks to remote control and monitoring center for storage and further processing.

For animal crossing detection, we studied sensing technologies using the laser sensors (following the break-the-beam strategy), motion sensors (following the area-cover strategy), and thermal infrared camera (following image processing and pattern recognition strategy). Our study reveals that effective sensing forms the most challenging aspect of such systems, particularly for a large environment and when the network nodes are power constrained. We conclude that the thermal infrared camera approach will not work because even with an expensive infrared camera (e.g., from FLIR Inc. and costs more than $50,000), an object of moose size in 1500 meters will yield effectively one pixel on the resulting camera images due to the resolution limitation. The other two approaches using laser sensors and motion sensors can work properly, however, their sensing range (typically in tens of meters) greatly reduces the coverage of each sensing node. Therefore, densely deployed roadside network is required, which inevitably increases the overall investment cost. However, for identified road sections with high animal crossing frequency, such technology provides a viable solution to address the roadside safety problem.

For prototype development and lab test, we designed a simple scenario of three-node relaying network in the laboratory settings to prove the working of the proposed idea, and we developed network protocols and data processing schemes for the system. Major design tasks include software design, hardware design, RF and antenna design, system integration and end-to-end verification, and performance tests. We designed the sensor node architecture to include the control and data processing unit, sensing modules, wireless transceivers, and power supply unit. We realized the senor node functionalities based on various microcontroller platforms to evaluate their performances in terms of ease of implementation, effectiveness, cost, and energy efficiency of the design. The platforms we have tested include the Texas Instrument (TI) microprocessor (MSP430 series) based evaluation board (MSP430F169), AVR ATmega series microcontroller (ATmega168), TI CC430F6137 based evaluation system, and the recent Raspberry-Pi based microcontroller platform. Short-range and low power radio transceivers are used for local data transmission among sensor nodes and between sensors and actuators. We compared Zigbee, RF, and Bluetooth options as the choices for the communications methods, and we determined to use Nordic nRF24L01+ RF transceivers for data transmission among sensor devices due to its low cost, ease of programming, and flexibility in interfacing with microcontroller boards.

The project has been served as a good platform for the training of highly qualified personnel. To date, we have had two master's students trained through this project (and successfully graduated). We have another master's student expect to complete his project by the end of this semester. We have had one Ph.D. candidate and one postdoctoral fellow worked on different aspects of this project. Other than HQP training, we have had four seminars during the training process, and we have had one engineering design paper published and presented at the *IEEE Newfoundland Electrical and Computer Engineering Conference* (*NECEC*), which was held in Holiday Inn, St. John's in November 2011. The funds for this project has been spent according to the budget outlined in the proposal.

We recommend the following directions as the future work of this project: (1) Effective and large-scale sensing technologies; (2) Using reconfigurable technology to enhance network functionalities; (3) Incorporate network self-test and self-diagnostic functions; (4) Field test of the proposed idea and network.

Presentations

1. **Title**: Demonstration Network Design of Wireless Sensor Based Wildlife Vehicle Collision Reduction Network

   Presenter: Yi Li

   Venue: The *20th IEEE Newfoundland Electrical and Computer Engineering Conference* (*NECEC'11*), Holiday Inn, St. John's, NL.

   Time: November 2011.

2. **Title**: Prototype design of sensor node for moose detection using wireless sensor network technology

   Presenter: Yi Li

   Venue: MASCE Seminar, Faculty of Engineering, Memorial University, St. John's, NL.

   Time: August 2011.

3. **Title**: Implementation of wild-life vehicle collision avoidance and alarm system using sensor network based technology

   Presenter: Ben Fang

   Venue: MASCE Seminar, Faculty of Engineering, Memorial University, St. John's, NL.

   Time: December 2011.

4. **Title**: Sleep mode dispatching and routing algorithm development and implementation on sensor nodes using Raspberry-Pi based sensor platform

   Presenter: Shi Runlin

   Venue: MASCE Seminar, Faculty of Engineering, Memorial University, St. John's, NL.

   Time: August 2012.

Publications and Reports

1. Y. Li, F. Ben, Z. Wang, and C. Li, "Hierarchical Wild Animal Detection and Notification System based on Wireless Sensor Networks -- Design and Implementation," In *Proc. of 20th IEEE Newfoundland Electrical and Computer Engineering Conference* (*NECEC'11*), St. John's, November 2011.

2. Y. Li, "Wireless Sensor Network Technology based Wildlife Vehicle Collision Reduction System," Internal Project Report, Memorial University, August 2011.
3. F. Ben, "Wireless Sensor Network: Wild Animal Detection and Notification System," Internal Project Report, Memorial University, November 2011.
4. R. Shi, "Wireless Sensor Networks: Moose Detection," Internal Project Report, Memorial University, March 2013.

HQP Training involved in the Project

1. Li, Yi, M.A.Sc. (project based), convocation in October 2011, worked on the prototype design of sensor node for moose detection on ARM processor based development kits using wireless sensor network technology
2. Ben Fang, M.A.Sc. (project based), convocation in May 2012, worked on the implementation of wild-life vehicle collision avoidance and alarm system based on Texas Instrument (TI) CC430 platform for sensor networking technology development.
3. Shi, Runlin, M.A.Sc. candidate (project based), expect to graduate in May 2013, worked on sleep-awake mode dispatching algorithm and routing algorithms development and implementation on sensor nodes using Raspberry-Pi based sensor platform.
4. Han, Shuai, PDF, September to November, 2012, worked on advising and project student co-supervision M.A.Sc. students projects. Contributions include providing instructions and tutorials on project development on various micro-processor/micro-controller based systems, and DE-II Altera FPGA based system development.
5. Zhang, Chen, Ph.D. candidate (2012.09-now), worked on routing algorithms and delay tolerant networking technologies for wireless sensor networks. Identified effective routing algorithms will be handover to project master's students for implementation.

Hierarchical Wild Animal Detection and Notification System based on Wireless Sensor Networks — Design and Implementation

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***Abstract*—With the development of regional economic and transportation system, more and more people in the world count on the vehicles to go out. At the same time, many highway systems are build across the habitat of the wild animals, so people's lives and property are threatened by the traffic accidents caused by the wild animals. As a result, the wild animal detection and notification system has drawn much attention in the research community of wireless sensor networks. As far as we know, all previous built wild animal detection and notification system have two disadvantages: one is the detecting sensors these systems are usually just equipped a single sensing technique, so the robustness of the sensor is unreliable; the other problem in previous system is they usually depend on additional equipments on vehicles to receive the notification of animals' approaching. In this paper, we propose a new hierarchical wild animal detection and notification system based on wireless sensor network, which can provide more reliability for sensors in atrocious weather and without requirement for users on additional devices on vehicles.**

***Index Terms*—hierarchy network, sensor network, demonstration network, wild animal detection, vehicle service**

I. Introduction

In developed countries, vehicle is the necessity for life. People count on vehicle to go to work and shop, or even travel the entire country by driving. Especially in the North America, people who are living outside the urban areas heavily depend on the highway system. However, North America highway system was sometimes built across the habitat of the wild animals [1], so people's lives and property are threatened by the traffic accidents caused by the wild animals. In the United States, the number of accidents caused by wild animals is up to 1 million per year and 30% of them cause the property damage over 1000 dollar, and the direct economic damage is up to 8 billion dollars in total. Moreover, data in [2] further indicates us that the proportion of accidents caused by wild animal in United States is increasing over years. Similar conclusion can be drawn in Canada by the statistical data in [3]. In particular, in 2003 the total number of the wild animal involved accidents is 39774 and the number still grows every year, and as the same time, the population of wild moose is increasing as well [3].

As the result, the wild animal detection and notification system has drawn much attention in the research community of wireless sensor networks. In fact, the effectiveness of sensor based detection systems have been tested in some countries. According to the work done by Huijser and McGowen in [4], the wild animal detection and notification system deployed in Switzerland can help drivers to avoid 81.53% accidents caused wild animal. In some particular areas, no wild animal involved accident happens after this kind of sensor networks deployed [4]. However, even thought the sensor networks can effectively reduce the collisions between vehicles and wild animals, additional equipments are usually required on vehicles to receive the warnings of wild animals. Furthermore, the sensors in existed systems are usually equipped with only one technique in detecting, so they may not work in atrocious weather. Hence, in this paper we try to propose a new kind of sensor networks. In general, our new wild animal detection and notification system has two features.

- Three kinds of nodes are used in our system: detection node, relay node, and sink node, so wireless nodes are working on different hierarchies in sensor network.
- We equipped multiple detection techniques on detection nodes to enhance its robustness.

The rest of this article is organized as follows.

II. Related work and motivation

Some animal detection systems have already been built to detect large animal approaching, and send out the alert to vehicles nearby. In these systems, two important components are usually used. One is the detecting module, and the other is the notification module.

1) The techniques used in detecting module can be separated into three categories which are passive area-cover detection, active area-cover detection, and break-the-beam detection.

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a) In passive area-cover detection, sensors are deployed in specific regions which are used to detect the infrared emitted by running engines, hot airflow, and animals. In particular, different kinds of objects have different levels of temperature, so the sensors can distinguish what is the object in its covered area.
b) In active area-cover detection the sensors will send microwaves to it detected area, just like a radar. By receiving the reflection of microwaves, the large animals can be detected.
c) In break-the-beam detection, transmitters send infrared, laser, or microwave to the receivers. When large animals go across the detecting region, the beam will be blocked or reduced, by which the animals can be detected.

However, each of the techniques introduced above has its disadvantages. First, the passive infrared sensors usually can only work in the conditions with temperature from 0°C to 60°C. According to the statistic data in [3], more traffic accidents caused by wild animals happened in winter than the summer. Hence, the passive area-cover detection is not suitable for cold weather in winter. Second, the active area-cover and break-the-beam detections are not suitable sometimes either. That is because even though the microwave and laser are less affected by the temperature compared to infrared sensors, the effectiveness of such two detecting techniques will be decreased by the rains and snows.

2) For the notification module, two techniques are widely used. One is based on customized on-board equipments and the other is based devices like GPS (Global Positioning System).
a) The customized on-board equipment is a receiver installed on the vehicle, and its transmitter side is in fact the sensor networks. When the sensor network detects large animals that may threaten the traffic, a warning message will be broadcasted. The receiver on vehicle will received the massage and alarm drivers the potential danger on the road.
b) For some sensor network, the messsges will be concentrated to based station, and the warnings will be separated to the GPS or other computational devices.

We can see that, both methods require additional equipments in the vehicle, which is the disadvantage in the existing system.

As the result, the motivation of our research is to build a system which can detect the large animals in atrocious weathers and provide notification service to all the vehicles.

III. Basic idea

Since only one detecting method cannot ensure the successful detection, we build three kinds of detection sensors in each detection node (DN). In this paper, these sensors are laser sensor, infra-red sensors, and temperature sensor. As shown in Figure 1, each detection node will utilize both area cover and break-the-line detection method. First, the

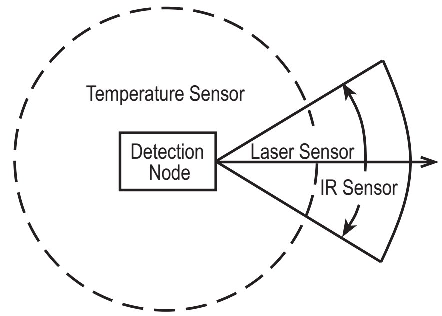

Fig. 1. Sensors on detection node

laser sensor which provides one single detecting line for the node can detect the motivation when objects move across the detecting line. Second, even though the detecting range of the infrared sensor is shorter than laser sensor, it is wider in both horizon and vertical direction. Third, the temperature sensor can supply the temperature signals for objects within the working circumstance of the node.

To make the system is suitable for all vehicles and independent from additional devices, to construct the sensor network in three hierarchies. It can be illustrated by Figure 2. The

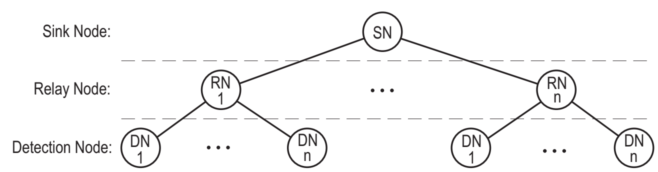

Fig. 2. Hierarchies in the system

detection nodes are in the bottom, they have the duty to report their detected information, operation conditions and power supply conditions up to the relay node (RN). A relay node may have many detection nodes in charge, and it controls their behaviors. Many relay nodes compose the middle layer in the hierarchy of our system, and they serve a single sink node (SN) in our system which is the top layer in the network. The sink node has the two functionalities: one is to cumulate the notifications that have been received by relay nodes; the other is lighten the yield signal beside the road as an alarm for drivers.

IV. Software and hardware implementations

In this section, we will present the details in our implementations. We first introduce the inner operations of the sensor network and fundamental protocol. After that, the algorithms for these operations will be talked about. In the last part of this section, we will present a demonstration with the hardware specifications.

A. Operations and protocol

In the sensor network we proposed, four important operations are defined: node incorporation, node condition query, node channel changing and release, and warning report. The first three of these operations are related with detection-relay nodes, and the last operation is between both detection-relay nodes and relay-sink nodes. In particular, the node incorporation defines the procedures to add a new detection node for a relay node; the node channel changing and release are to change and release the wireless channel for detection-relay node pairs and synchronize them; the node condition query triggered by relay nodes is to query the detection node's conditions; and the warning report is propagate from lower to higher hierarchy nodes, until the sink node receives the warning detected by bottom layer.

Considering the reliable data transmission is necessary to maintain an effective system, all the packets transmitted between nodes should be acknowledged by the receiver except the acknowledgement (ACK) itself. If no ACK is received by the transmitter from intended reciver, the transmitter have to retransmit the last packet again until the ACK is received.

The rest of Section IV-A will focus on the details of packets' formats which are used to accomplish the operations introduced above.

1) Node incorporation is initiated by a new detection node, and it cannot join in the sensor network until it is assigned a node number by the relay node on the upper layer. The entire procedure can be presented by a communication sequence that *Join Request-ACK1-Join Reply-ACK2*. In our implementation, we assume for any time, there is only one detection node that wants to join in the network. Hence, we only use an 8 bits command to be the Join Request packet, and the packet format of Join Relay is presented in Figure 3. The *source ID* is the relay node ID, and the *destination ID* is usually set to be "11111111" which means the packet is a broadcast packet. Note only one new detection node is considered, the node which has just transmit the Join Request will received the broadcast packet, and the *new node ID* is in fact the assigned ID for the new node. Other jointed nodes will ignore the overheard Join Reply packet. The format of ACK will be talk about later.

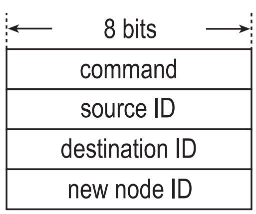

Fig. 3. Packet format of incorporating new detection node

2) Node condition query is triggered by the Condition Request sent from the relay node with designated detection node ID, and the designated detection node should send back the Condition Report and Condition Information. The entire procedure can be presented by a communication sequence that *Condition Request-ACK1-Condition Report-ACK2-Condition Information-ACK3*. The packets' formats of Condition Request and Condition Report are the same which is presented in Figure 4, and the packet's format of Condition Information is shown in Figure 5. All the meanings of the fields in these packets are explained by the field name, so here we need not explain them again.

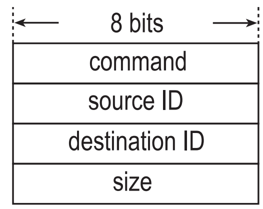

Fig. 4. Packet format of condition request and condition report

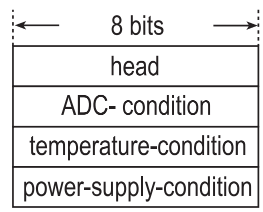

Fig. 5. Packet format of condition information

3) Node channel changing and release are the exclusive features in our system, and they are operated separately before and after the node condition queries. To make the procedures more easily to be understood, we first talk about the channel assignment in our system. Two kinds of channels exist in our system: one kind is public channel which is a single channel shared with all nodes in the network; the other kind is private channels which are the channels assigned for a pair of detection-relay nodes. To save channel resources, the nodes in our system are usually working in the public channel, unless they need to accomplish the duty of node condition query, and all nodes will maintain a table to record the channels that are being used right now. In particular, before the node condition query, the relay node need to send out a Channel Changing packet to the intended detection node. After the detection node transmit the ACK back, both the relay node and the detection node will move to a private channel indicated in the Channel Changing packet. Other nodes which successfully overhear the Channel Changing packet will mark that the assigned private channel is being used and avoid to use the channel again. When the node condition query process is finished, the relay node will send out the Channel Release packet to the intended detection node, after the detection node sends back the ACK, they will move back to the public channel. As

well, other nodes that successfully overhear the Channel Release packet will remove the corresponding mark for that private channel in their channel table, which means that channel can be reused for further network operations. The packets used for Channel Changing and Release have the same packet format which is presented in Figure 6. The *channel index* field is the index of available channel that the relay node want to change or release, and because other field can be self-explained, we will not further introduce them.

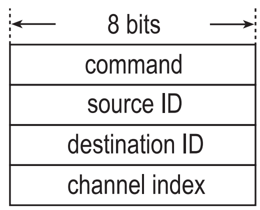

Fig. 6. Packet format of channel changing and release

4) Warning report is transmitted by the detection nodes and propagated up to their relay node. Finally, the warning report will be received by the sink node on the top of the entire network. Because once the potential threaten is detected, the information should be reported to the sink node, we do not care about which sensor node the warning comes from. Hence, in our system the warning report just has a single byte from detection node to relay node, and finally reach the sink node. The only issue we need emphasize here is the ACK must be transmitted from upper layer to lower layer when the upper layer node receives a warning report.
5) From all above introductions, we can see the ACK packets are widely used. In our implementation, we just ask the receiver to transmit the last byte it received back to the transmitter as an ACK packet.

B. Software specification

According to the operation we defined in Section IV-A, we specify two important algorithms here.

1) Dynamic channel selection algorithm. In order to lower the power consumption for each detection node and avoid the interferences among detection nodes, in this paper, the programmable communication channel register RF_CH of the radio frequency (RF) transceiver is utilized. In each node (relay or detection), a channel table will be first created. This table has an array with 62 elements and each element has 8 bit data. All the last six bit of the elements indicates the selectable channel. The initial value of the first two bits of each element which indicate the availability of the channel is set to "11".
   When the relay node and one detection node want to build the connection in order to transmit the condition information, the relay node will check the available channel in the channel table. After selecting one channel, the first two bits in its channel table will be set as "00". Then by sending channel change packet, the relay node not only informs the connecting detection node to change its RF channel but also broadcasts the modification of the availability for the selected channel. Then all detection node will update their channel table and set the first two bits of the relative element in the array as "00".
   When the condition reporting finish, the relay node will first inform the connecting detection node to release the selected channel and return to the public one by sending the release channel packet via the selected channel. Then both the detection node and the relay node will return to the public channel and set the first two bits of the relative channel elements in the channel array to "11". By sending the Channel Release packet again via the public channel, the relay node informs all detection nodes to update their channel table and set the availability bits as "11".
   Moreover, the connection between the sink node and the relay node will utilize an exclusive channel which is not available for the detection nodes
2) Node joining algorithm. A variable "sens_num" will be created in each relay node which is initialled as "0000 0001". When the relay node receives the Joining Request packet, the "sens_num" will add one. Then the "sens_num" can be sent as the node number which is included in the assign node packet to the new joining detection node.
   For the new joining detection node, its node number is initialled as "0000 0000". It will keep sending Joining Request packet until receiving the assign node packet. Then the node number will be set as the number in the Join Reply packet. When receiving packets from relay node, this assigned node number can be utilized to determine if it is the *destination ID* of the packet. On the contrary, this node number is the *source ID* in the packets which are sent by the detection node itself.

C. Hardware specification

To build the detection node, we first chooses port 6 as the ADC converter and the infrared and laser sensors are connected to port 6.1 and 6.2. In addition, port 6.3 will connect with the on-board temperature sensor. The ports 7.1 to 7.3 are utilized as the SPI communication ports which are connected with MOSI, MISO and SCK ports on nRF24L01. The ports 8.3 and 8.4 on MSP430FG4619 are used as general I/O ports in order to generate the control signal to the ports CE and CSN. The IRQ pin on RF transceiver is connected with port 8.5 on MSP430FG4619.

For the relay node, it utilizes MSP430FG4619 with nRF24L01 to achieve the function of receiving information from all detection nodes and transmitting the warning information to the sink node. Comparing to the detection nodes, the relay node does not use the ADC ports but remains the connection between the evaluation board and the RF transceiver by utilizing I/O and SPI ports. In the implementation, I/O port 5 will be set as the output ports and connect the LED light to indicate receiving warning signal from the detection nodes.

The MSP430F169 is used for the sink node. It connects with the same RF transceiver which is utilized for the detection nodes and relay node. The port 4.0 to 4.2 will connect to CE, CSN and IRQ in the RF transceiver. The ports 7.1 to 7.3 are utilized as the SPI communication ports which are connected with MOSI, MISO and SCK ports on nRF24L01. The sink node only receives the integrated data from the relay node when the warning information is issued by the detection node. In our implementation, in order to verify the warning signal transmission, the sink node will use the same amount of LED lights which will be connected to port 4.3 to 4.5 to indicate the integrated warning signal sent by the relay node.

V. Concluding remarks

Based on the design targets and components which described in Section III, both the hardware and software designs for the demonstration network of wireless based wildlife vehicle collision reduction network are described by the paragraphs described above. In this project, the three-level demonstration network is built by utilizing the MSP430 family evaluation boards, sensors and RF transceivers. For the communication algorithm, the methods of dynamic channel selection, node discovery, data transmission and warning signal reporting are shown in Section IV. This demonstration network is a wireless sensor based wild animal detection and notification system. For the future work, the algorithm to discard a node with lower power supply and node replacement is necessary. Because the communication in this project is based on directly transmission between two nodes, an efficient routing algorithm which contains the multi-hop data transmission and communication between each detection node can be utilized. So that the whole system can be more flexible to meet the real wild environment conditions.

References

[1] U. D. of Transportation, “Wildlife-Vehicle Collision Reduction Study,” *Report to Congress*, August 2008.

[2] S. M. Oosenbrug, E. W. Mercer, and S. H. Ferguson, “Moose-Vehicle Collision in Newfoundland — Management Considerations for the 1990s,” *Department of Environment and Land, Newfoundland and Labrador Wildlife Division*, 1991.

[3] L.-P. T. . A. Inc., “Update of Data Sources on Collisions Involving Motor Vehicles and Large Animals in Canada to Transport Canada Road Safety Directorate,” August 2006.

[4] M. P. Huijser and P. T. McGowen, “Overview of animal detection and animal warning systems in North America and Europe,” *UC Davis: Road Ecology Center*, August 2003.

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