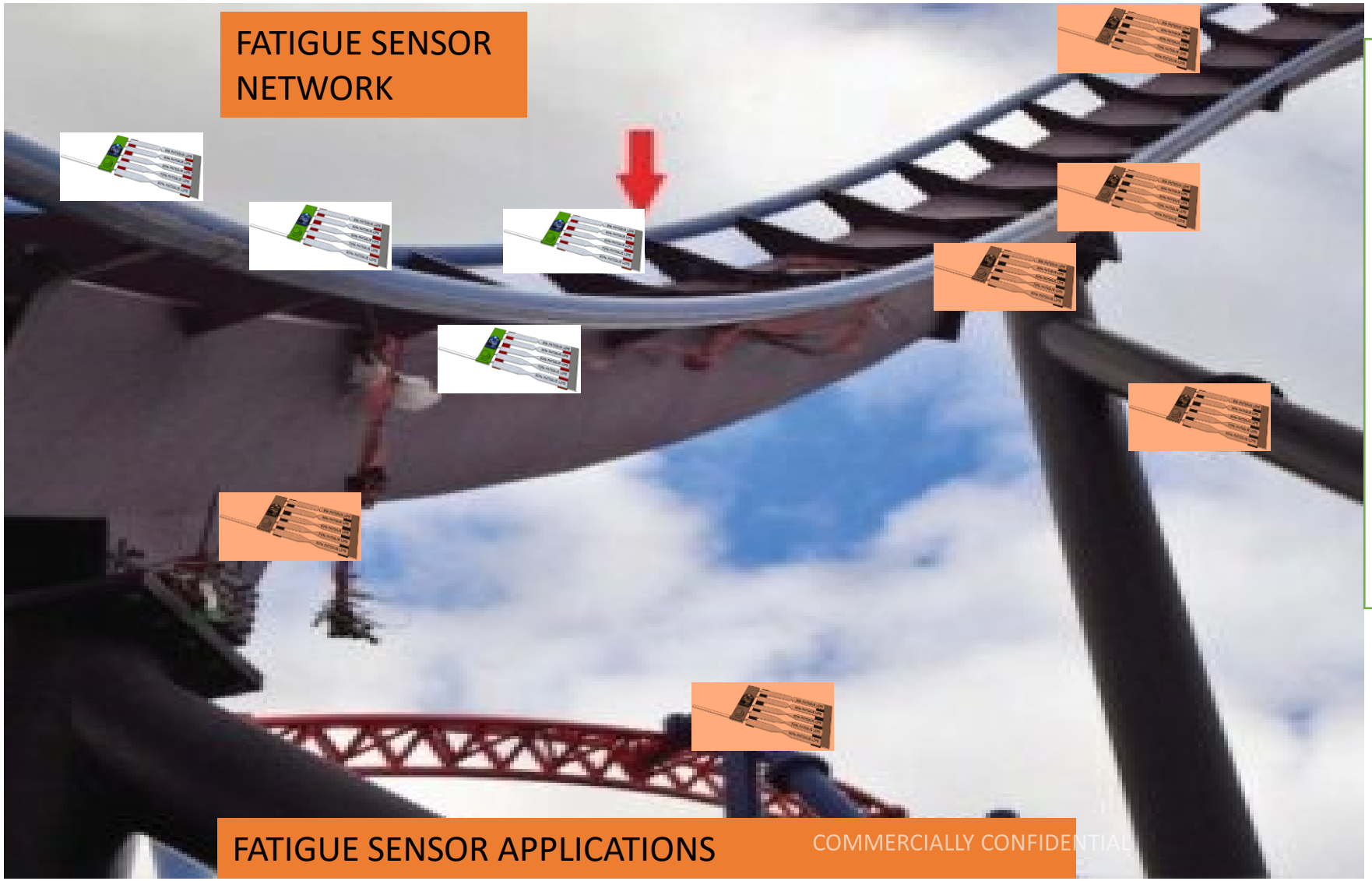
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
and
Wireless SHM-RFID-IoT Smart Fatigue Damage SENSOR NETWORK
and
An Internet of Things-IoT Based Intelligent Predictive Maintenance Management System
(FOR COASTER PARK STRUCTURES APPLICATIONS)

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (COASTER STRUCTURES APPLICATIONS)



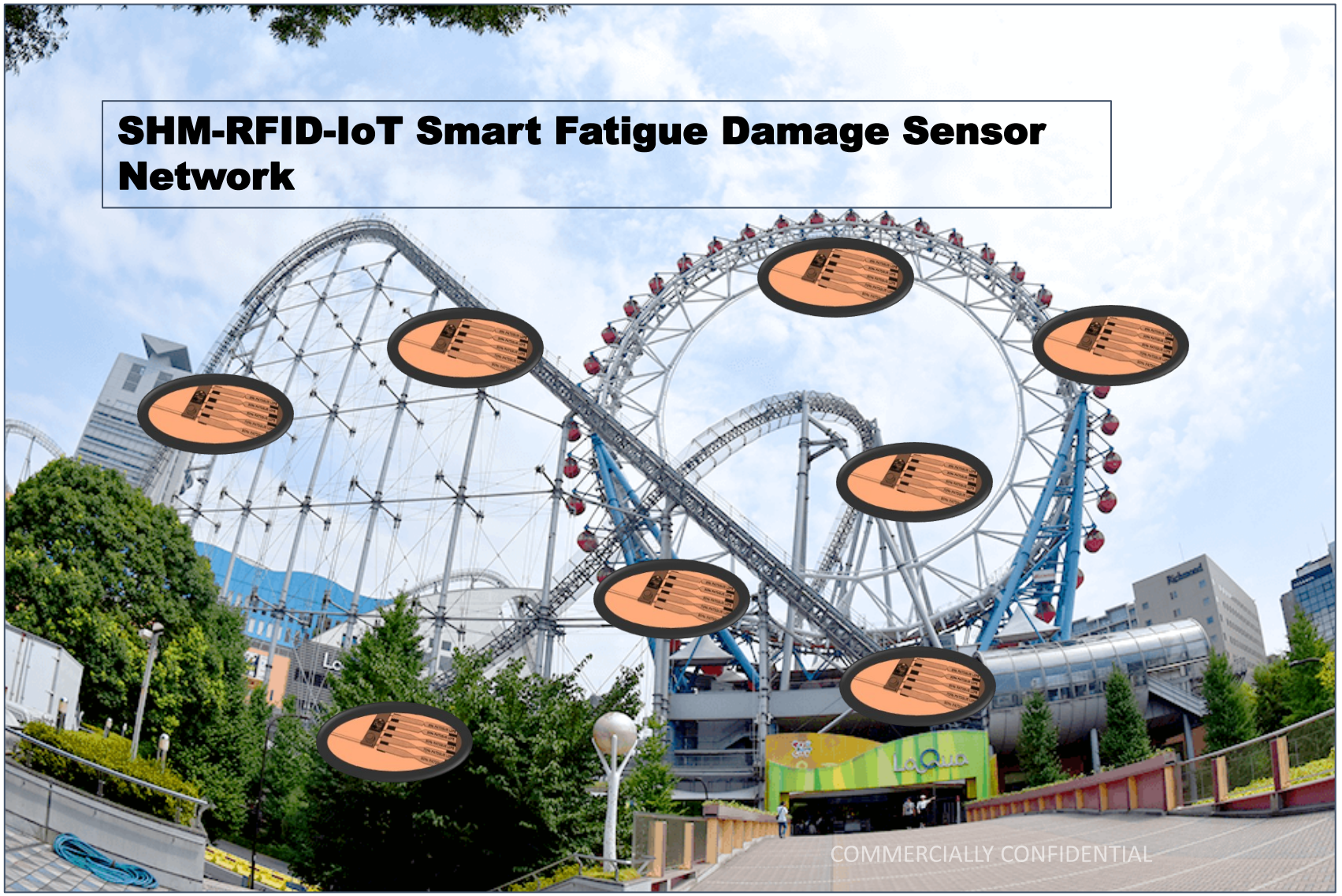
STRUCTURAL FATIGUE DAMAGE MONITORING of different components of COASTER STRUCTURES SYSTEMS (welded, rivets, bolted, and other fatigue specific-sensitive elements) during normal service.

Motiongate Dubai

Motiongate Dubai

Dubai
Observation Wheel

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (APPLICATIONS)



DISTRIBUTED SENSOR NETWORK FOR SHM SYSTEM.
FATIGUE SENSOR APPLICATIONS TO COASTER STRUCTURES:
Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..

COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor

(SHM COASTER STRUCTURES APPLICATIONS-SENSORS)

Identify all the Fatigue Critical HOT SPOTS in STRUCTURES for the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

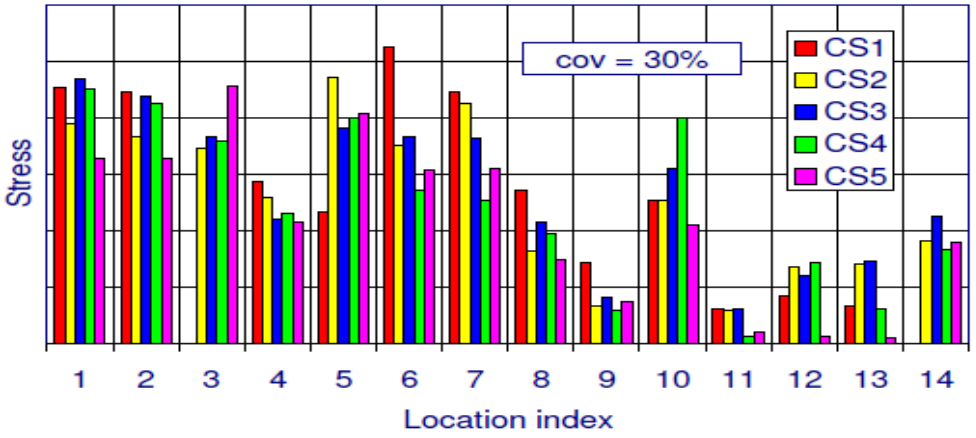


Figure 6. Stress prediction benchmark – stress results

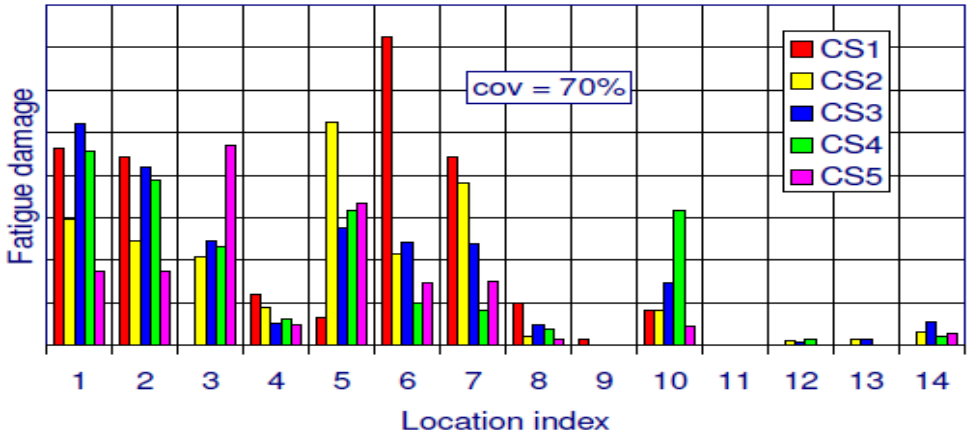
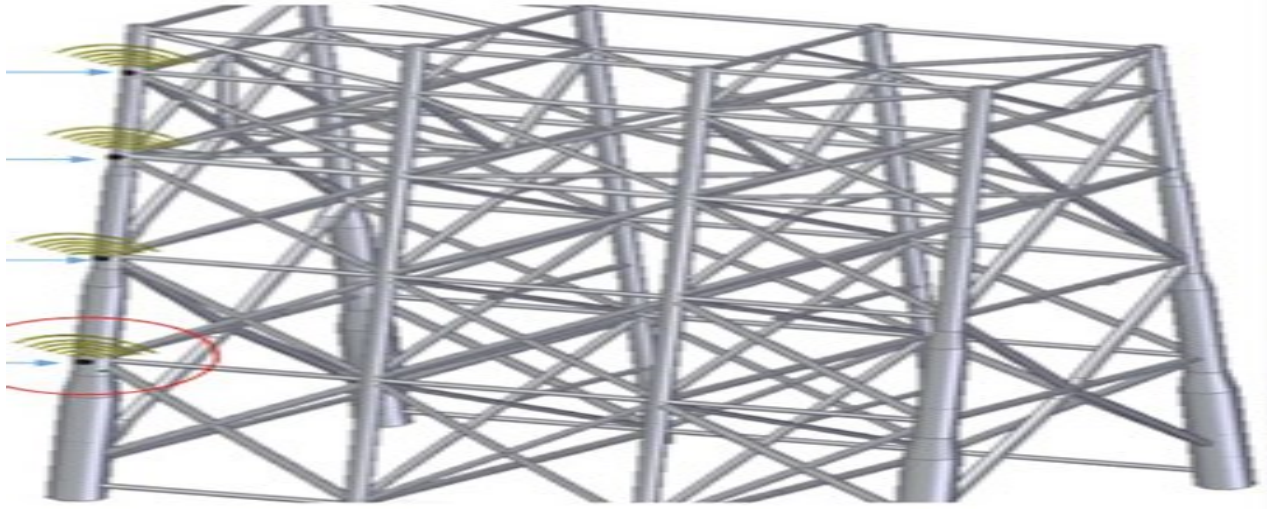


Figure 7. Stress prediction benchmark – lifetime results

Fatigue Critical HOT SPOTS in SHIP STRUCTURES for the applications of fatigue damage sensors FDS in order to monitor the RESIDUAL FATIGUE STRENGTH or CUMULATIVE FATIGUE DAMAGE INDEX



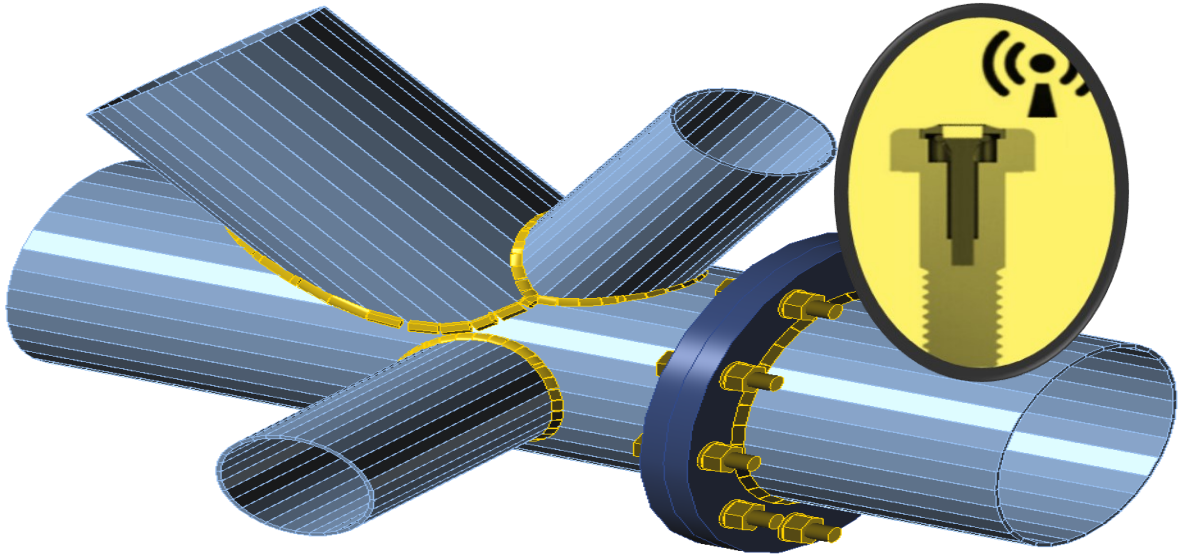
Wireless Enabled RFID-IoT SMART BOLT (SENSOR)

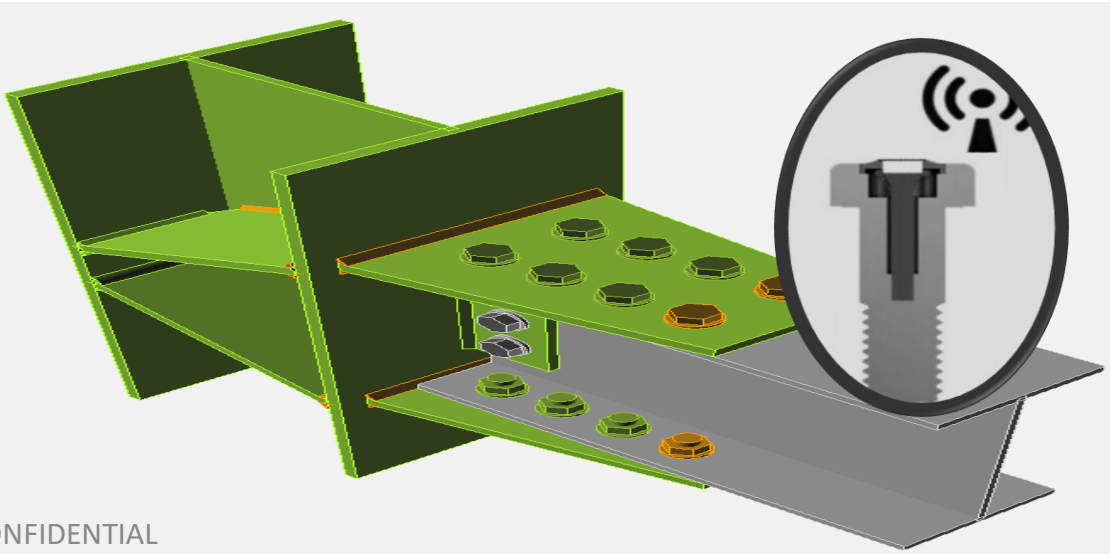
- **Bolt type assemblies(Joints) are commonly used in many industrial applications of large and complex structures like pipelines, cranes, mining machineries, COASTER STRUCTURESs, roller coaster structures etc. The main function is to maintain the right load and to ensure the safety and reliability of the structure.**
- **Many large and complex structures under dynamic and vibratory loading conditions like wind turbines, oil and gas installations, cranes, rail systems, oil platforms are subjected to cyclic heavy loads. Today's manual methods for controlling and maintaining bolts are very time consuming and costly.**
- **For these kind of reasons, developing an effective, and smart monitoring system is critical importance for Structural Health Monitoring.**

COMMERCIALLY CONFIDENTIAL

Wireless Enabled RFID-IoT SMART BOLT (SENSOR)

- **Achieving and maintaining the correct installed design tension will eliminate failures from fatigue, vibration loosening, structural slip and pressure containment**
- **85-90% of all bolted joint failures can be attributed to low bolt tension on installation tightening.**
- **During traditional tightening, the tension being achieved is unmeasured – it is the tightening force being applied (torque) that is measured.**
- **There is no reliable correlation between the equipment tightening power and the residual bolt tension achieved.**





COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor

(BOLT APPLICATIONS-SENSORS)

DISTRIBUTED SENSOR NETWORK FOR COASTER STRUCTURES SHM SYSTEM.

FATIGUE SENSOR APPLICATIONS TO COASTER STRUCTURESS:

Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..

COMMERCIALLY CONFIDENTIAL

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

- **A Novel Smart RFID Fatigue Damage Sensor aiming to the prediction of fatigue residual strength of critical mechanical and structural components for Structural Health Monitoring has been DEVELOPED and PATENTED (Patent N0. US 8,746,077 B2).**
- **The proposed smart sensor system is designed for early detection and estimation of the structural health cumulative fatigue damage level and wirelessly transferring the information using an active or passive RFID integrated system.**
- **The developed RFID fatigue sensor system has a specially designed geometry with multiple parallel oriented unidirectional, bidirectional or multi directional breakable C, U or V type notched beams having different fatigue lifetimes to predict not only unidirectional or bidirectional fatigue damage but also multidimensional cumulative fatigue damage level of structural or mechanical elements including composite structures.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

- **Whenever a particular beam of the sensor exceed the engineered number of fatigue cycles, the beam fails and sensor electronics detect that failure and transmit this information wirelessly.**
- **Having multiple beams that are designed to fail after precise number of fatigue cycles enables the health state of the structural member to be monitored. It gives ample warning about the health of the component so that necessary corrective measures can be taken.**
- **The sensor is quite lightweight with only several grams of weight and small in size slightly bigger than a credit card.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

- **Fatigue plays a critical role for design of structures or critical mechanical systems under cyclic dynamic loads. Several fatigue design methodology are used for fatigue design of mechanical components or structures. All these techniques are relied on STOCHASTIC MEDHODOLOGIES.**

- **Any failure in one of the structural members of the system causes catastrophic failure with serious consequences costing lives and property.**

- **Health status of structural members which undergo cyclic stress need to be monitored continuously and fatigued parts need to be replaced well before the failure limit is reached. Railway Systems, Aircrafts, Helicopters, Wind Turbines, Mega Cranes, and Marine Vessels are especially considered as systems vulnerable to this sort of fatigue damage accumulation.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

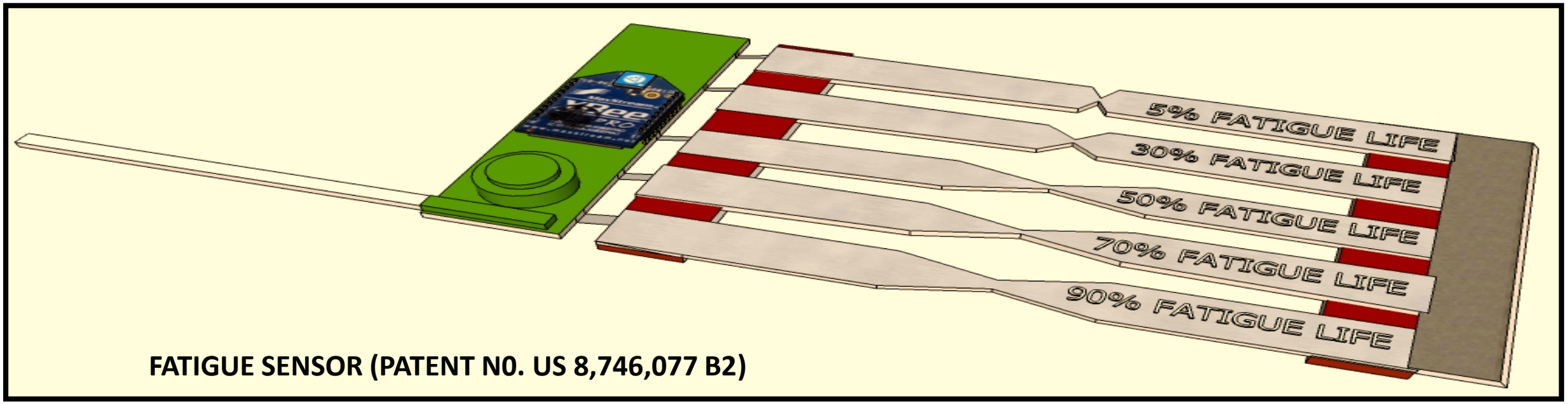
- **It is foreseen that the proposed RFID-IoT Smart Fatigue Sensor will revolutionize the concept of fatigue design and also will revolutionize the fatigue inspection and maintenance management methodologies by using the RFID-IoT Smart Fatigue Sensor Network Data.**

- **Since the distributed fatigue sensor network system periodically or continuously is monitoring the fatigue health state conditions of structures, the database of the sensor network system will be used for condition based inspection, sensor based maintenance management and development of new fatigue design tools for fatigue sensitive complex and large engineering structures or mechanic systems.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

- **The Figure shows the RFID FATIGUE DAMAGE SENSOR with 5 sacrificial beams members with fatigue life ranging from 10 % to 90 %.**
- **The 5-10% fatigue life mini-micro beam member is designed to be a "self-check" mechanism and designed to fail quickly if installed properly. Any sensor with 5-10 % finger not failing within reasonable time of installation is an indication of improper installation or faulty sensor.**
- **Failure-Fracture detection of the mini beams is done by sensing continuity of current passing through the beams.**

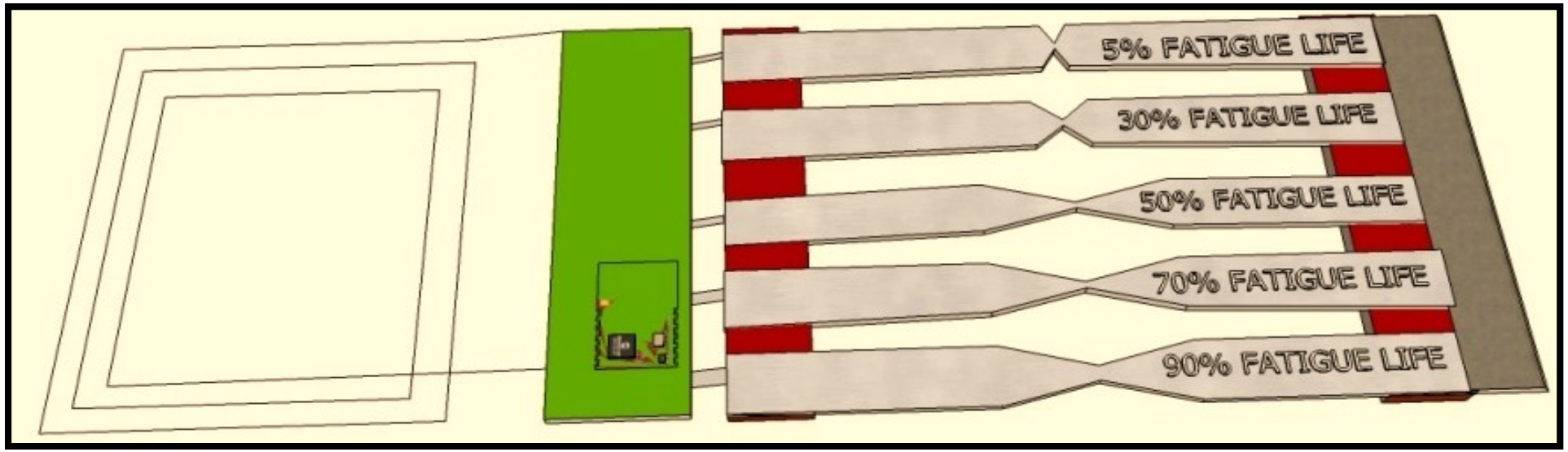
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (ACTIVE SENSOR MODEL)



FATIGUE SENSOR (PATENT N0. US 8,746,077 B2)

There are two versions of the fatigue sensor, one with a battery version and another one which works with RF power. The one with the battery uses Zigbee or similar low power sensor networking to interrogate the sensor about the state of breakable fingers. The sensor nodes relay information from one node to the other to communicate with the master node.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(PASSIVE SENSOR MODEL)



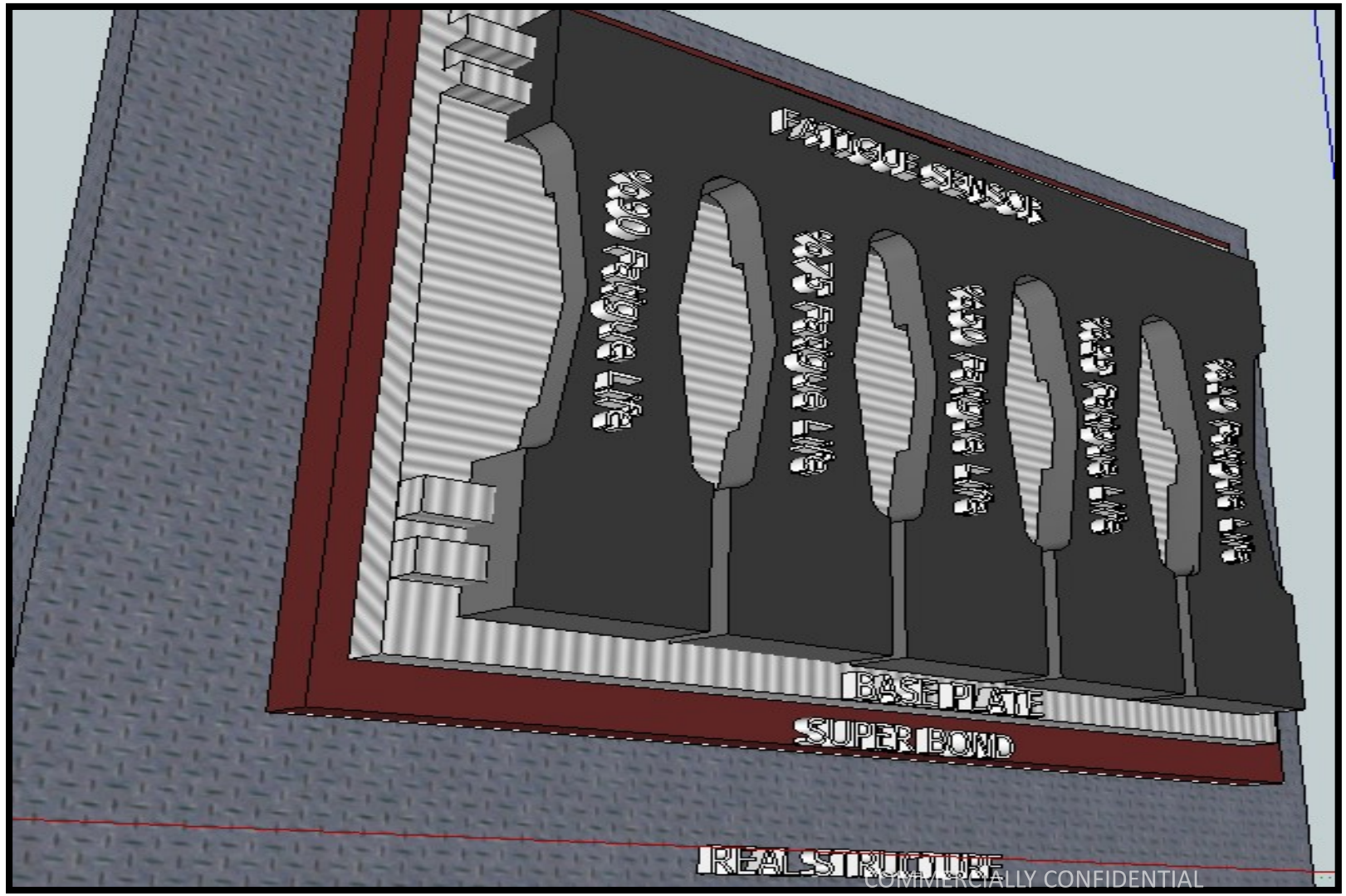
Fatigue Sensor (Patent N0. US 8,746,077 B2)

The sensor with no battery is shown in figure. This type is powered by RF power emitted by the interrogation wand. Interrogation distance of RFID type devices depend on both transmitter power and the coil size of the receiver.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network
(AS A NEW TYPE FATIGUE DAMAGE SENSING NDT MODEL)

- **Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor is a novel smart methodology of Non-Destructive-Inspection (NDI) in order to monitor the structural integrity.**
- **Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor will be used for intelligent inspection, maintenance and maintainability. E.g. studies are predicting a maintenance cost reduction by up to 75% on Service Bulletin (SB) level and a clear increasing of the system availability [1].**
- **Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor will be used to develop new methods and concepts for fatigue structural design, which can reduce the weight of structure for metal and composite structures up to 15% on component level.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (APPLICATIONS TO STRUCTURES)



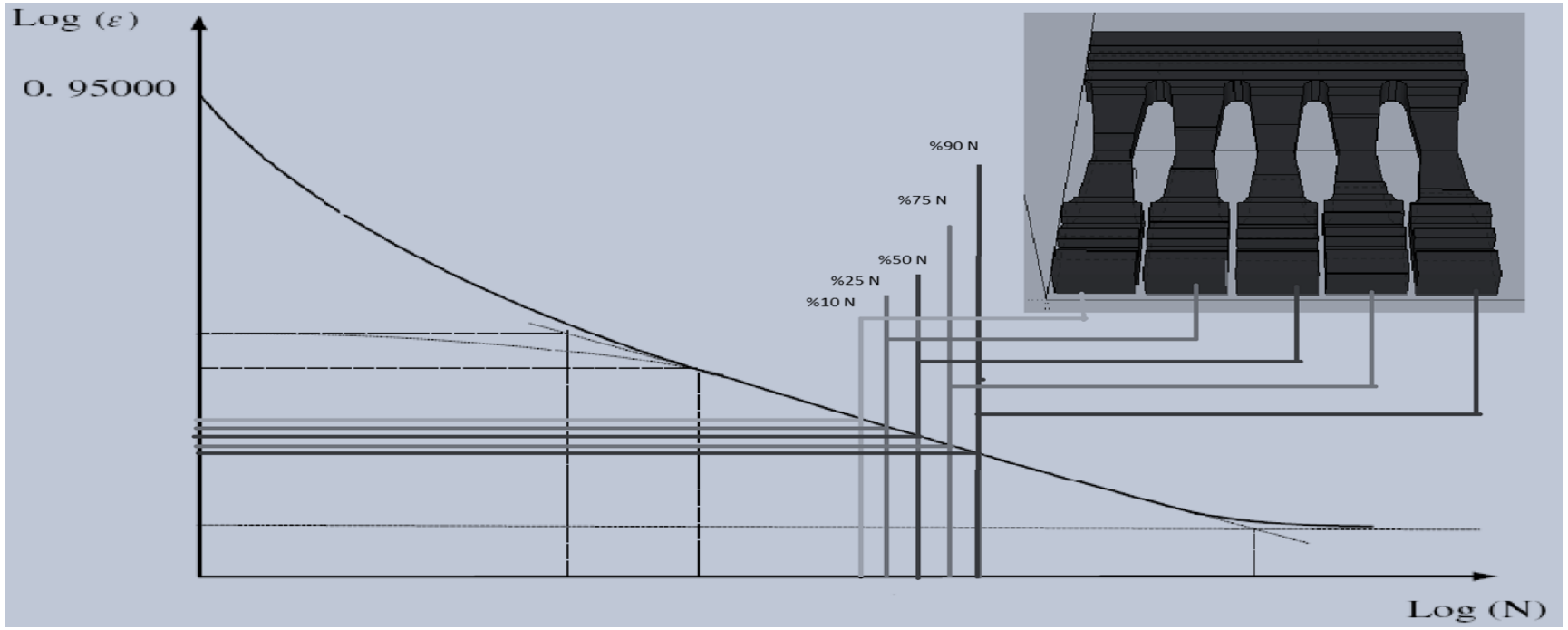
The fatigue sensor is designed to be attached to the surface by a special super bond very similar to strain gage attachments.
The sensor is mimicking the strains-stresses encountered by the structural member during its entire lifetime, and gives a live indication of remaining lifetime in a wireless manner depending upon the level of the fatigue cumulative damage indexes (Fatigue Life Cycles %10 N, %25 N, %50 N, % 75 N, %90 N)

COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(APPLICATIONS TO STRUCTURES)

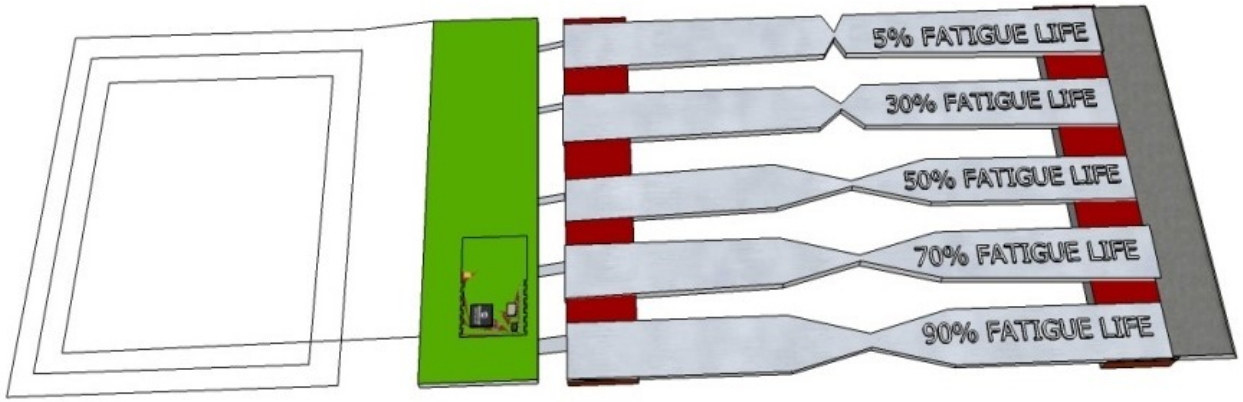
- **Identify all the Fatigue Critical HOT SPOTS in STRUCTURES for the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime. Specific and Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..**
- **Determine of maximum critical STRESSES in all the Fatigue Critical HOT SPOTS in STRUCTURES(Bolted and Welded Joints) by using FEA numerical model of the structure for the applications of smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime Monitoring.**
- **Development of Fatigue Model or Models of the selected FATIGUE SENSITIVE HOT SPOTS and Virtual FEA-Numerical Modeling and Analysis of the whole structure.**
- **Determine also the multi axial stresses acting locations and Find the principle stresses and directions for the applications of the sensors.**

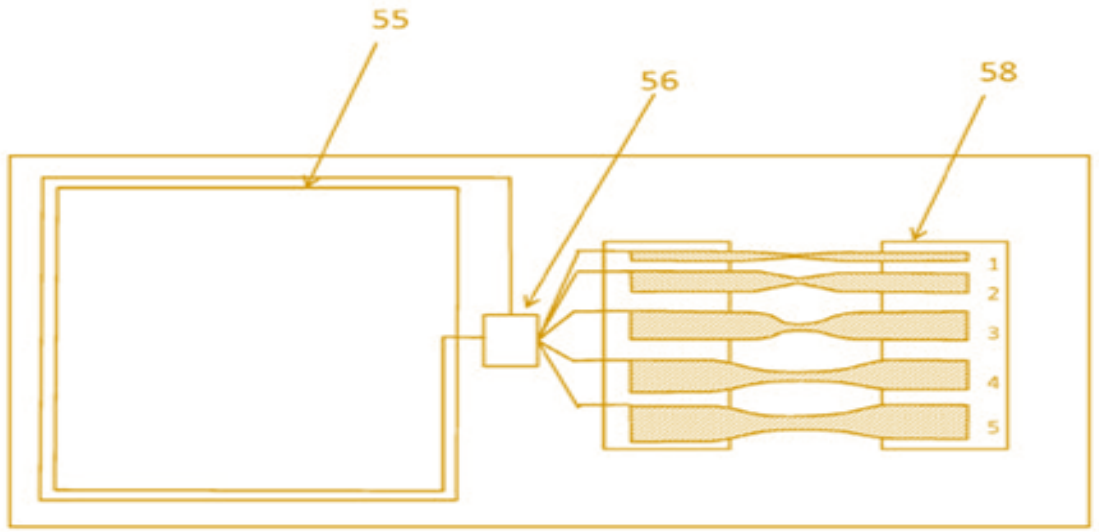
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(STRAIN BASED FATIGUE DESIGN)



The FATIGUE DAMAGE SENSOR mini beams are designed according to STRAIN BASED FATIGUE DESIGN APPROACH. The fatigue sensor with parallel mini beams having different fatigue lifetimes %10 N, %25 N, %50 N, % 75 N, %90 N- Total Lifetimes.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (PASSIVE SENSOR MODEL)

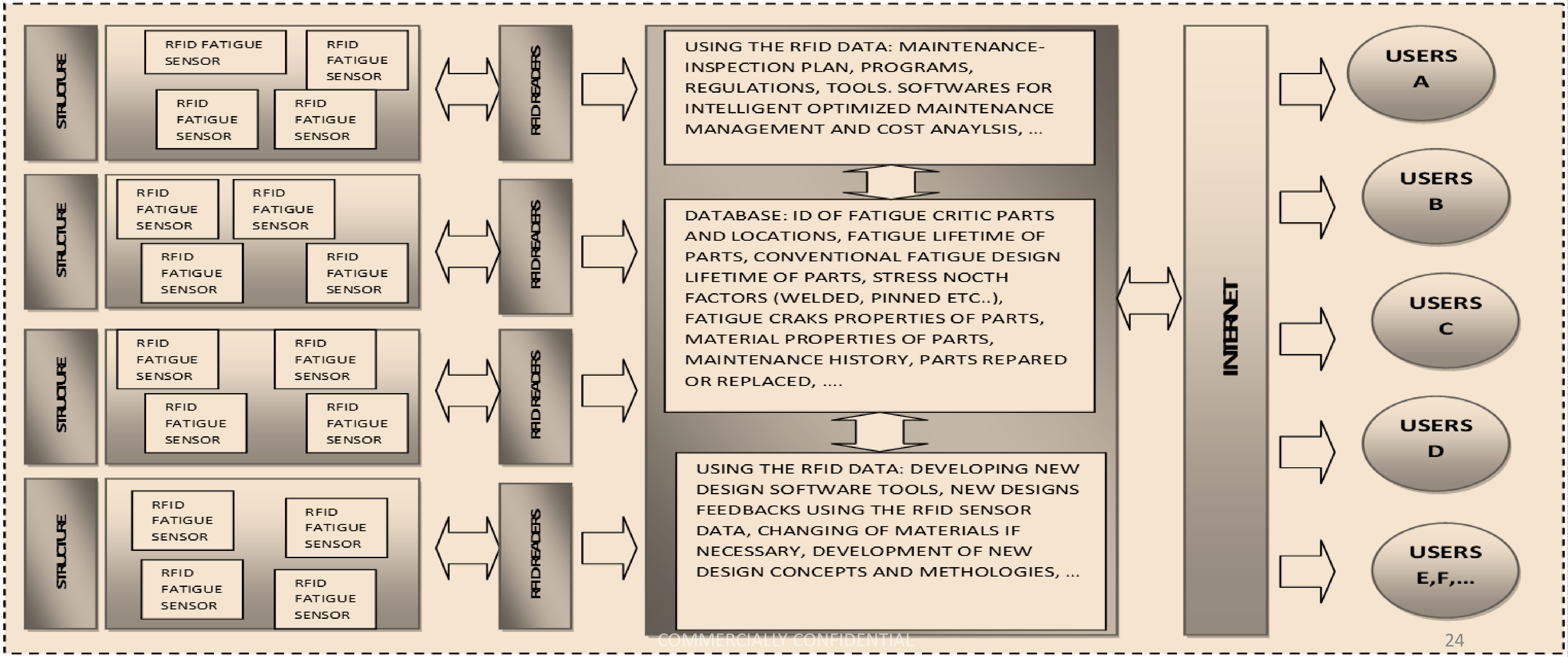




Fatigue Sensor (Patent N0. US 8,746,077 B2)

The sensor with no battery is shown in figure. This type is powered by RF power emitted by the interrogation wand. Interrogation distance of RFID type devices depend on both transmitter power and the coil size of the receiver.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (IoT SYSTEM MODEL)



COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (DISTRIBUTEDSENSOR NETWORK DATABASE)

DATABASE:

The RFID Fatigue Sensor System collects;

The operational lifetime history of each fatigue critical component or location, the fatigue properties of the critical part, the type of fatigue cracks, the maintenance history, the fatigue maintenance history of each critical location or component, the fatigue sensitive details of the structure, the component manufactured time, the manufacturer of the part, the ID number of the component, the part and critical connections., the part expected scheduled repair time, the part material properties, the part redesign needs and design modification or revision, the part connection properties(rivet, welded, lap joints etc..), the parts repaired or replaced, the parts expected service lifetime, the parts crack lengths and many more useful information of structures.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(INTELLIGENT CONDITION BASED MAINTENANCE MODEL)

CONVENTIONAL STRAIN GAGE USED FATIGUE DESIGN AND SCHEDULED-PLANNED BASED MAINTENANCE OF STRUCTURES

PERIODICAL SCHEDULED-PLANNED BASED INSPECTION-CHECK DURING NOT IN SERVICE. FOR FATIGUE INSPECTION OF STRUCTURES, CRACKS SHOULD BE VISIBLE OR DETECTABLE CHECKING FOR ANY REPAIR OR MAINTENANCE CASES.

FATIGUE INSPECTION OF STRUCTURES WITH CONVENTIONAL STRAIN GAGE BASED DESIGN, FATIGUE CRACKS SHOULD BE VISIBLE OR DETECTABLE. HEALTH STATE OF STRUCTURES IS NOT KNOWN. A FULL SCALE FATIGUE TESTING OF STRUCTURE REQUIRED TO IDENTFY THE CRITICAL AREAS AND FATIGUE LIFETIME OF CRITICAL PARTS.

CONVENTIONAL STRAIN GAGE BASED INSPECTION-MAINTENANCE RELIES ON PERIODICAL SCHEDULED-PLANNED INFORMATION OR INSPECTION. CHECKING HEALTH STATE OF STRUCTURES IS MEASURED BY VISIBLE OR DETECTABLE SIGNS OR INSPECTIONS AND ALSO PROJECTED LIFETIME INFORMATION

RFID FATIGUE SENSOR AND PREDICTIVE-CONDITION BASED STRUCTURAL HEALTH MONITORING AND PREVENTIVE MAINTENANCE OF STRUCTURES

RFID FATIGUE SENSOR BASED CONDITION MONITORING OF STRUCTURAL HEALTH STATE. CONTINUEOUS OR PERIODIC CHECK OF STRUCTURES DURING OPERATION (IN SERVICE) FOR ANY REPAIR OR MAINTENANCE CASES DO MIANTENANCE BASED ON SENSOR DATA WHICH SHOWS THE HEALTH STATE OF STRUCTURE.

CUMULATIVE FATIGUE DAMAGE INDEX OF RFID FATIGUE SENSORS IS MIMICKING STRUCTURAL HEALTH STATE (CUMULATIVE FATIGUE DAMAGE INDEX) OF STRUCTURES. % 90 USAGE OF LIFETIME OF STRUCTURES OR TOTAL CUMULATIVE FATIGUE DAMAGE INDEX REACHES TO 0.9. PARTS CAN BE REPAIRED OR REPLACED.

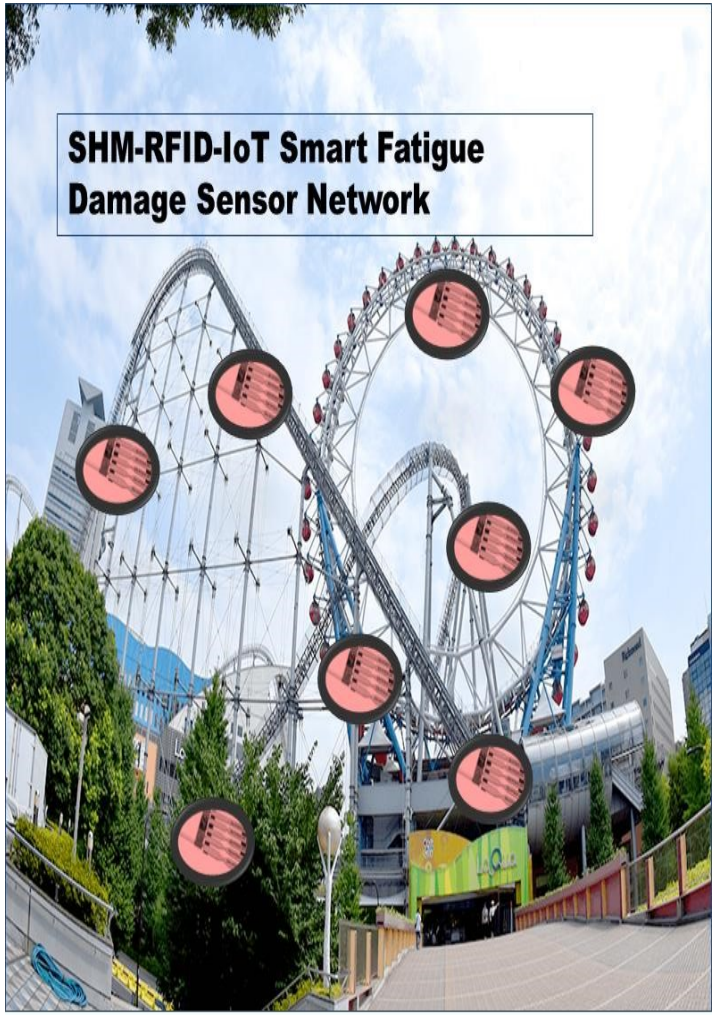
RFID FATIGUE SENSOR BASED CONDITION MONITORING SHM SYSTEM RELIES ON THE SENSOR DATA.WHEN THE RFID SENSOR LIFETIME REACHES TO % 90 CYCLES OR TOTAL CUMULATIVE FATIGUE DAMAGE INDEX REACHES TO 0.9. THE STRUCTURAL PARTS CAN BE REPLACED OR REPAIRED. INCREASES RELIABILITY AND REDUCES MAINTENANCE COSTS

COMMERCIALLY CONFIDENTIAL

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(INTELLIGENT CONDITION BASED MAINTENANCE MODEL)

SOFTWARE FOR INTELLIGENT MAINTENANCE MANAGEMENT FOR STRUCTURAL FATIGUE HEALTH MONITORING OF A UNIT AND A FLEET

- **The required maintenance decisions and the health state of critical parts of structures are given according to the RFID Fatigue Sensor Network data. The RFID Fatigue Sensor network information is mandating, the time of the fatigue damaged parts or locations should be repaired or replaced.**
- **Therefore, the proposed RFID Fatigue Sensor based Intelligent Predictive-Condition Based Maintenance Model is very efficient and effective strategic system since it increases service life and reliability and reduces maintenance and operations expenses.**
- **The proposed RFID Sensor Based Structural Health Monitoring and Maintenance Strategy are based on the periodic or real-time sensor information to optimize maintenance resources.**



A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(INTELLIGENT CONDITION BASED MAINTENANCE AND LIFECYCLE MANAGEMENT MODEL)

Do maintenance based on the state of the structure as need arises

Increases availability

Reduces maintenance costs

Increases reliability

THE LIST OF RFID CHIPS STORED STRUCTURAL FATIGUE MANAGEMENT INFORMATION OF EACH FATIGUE CRITICAL PART OF RAIL STRUCTURES

a) The operational history of each critical component

b) The maintenance or fatigue maintenance history of each component

c) The information related to the configuration of the AICRAFT PARTS in which the component is installed

d) The date the component manufactured

e) The name of the supplier of the component

f) The serial number of the component

g) The part number of the component.

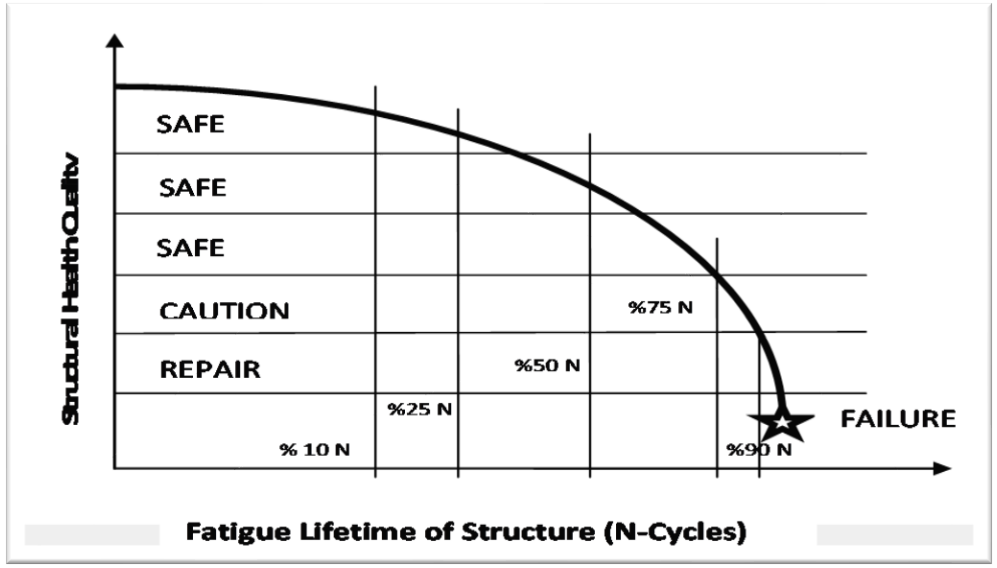
g) The part expected scheduled repair time

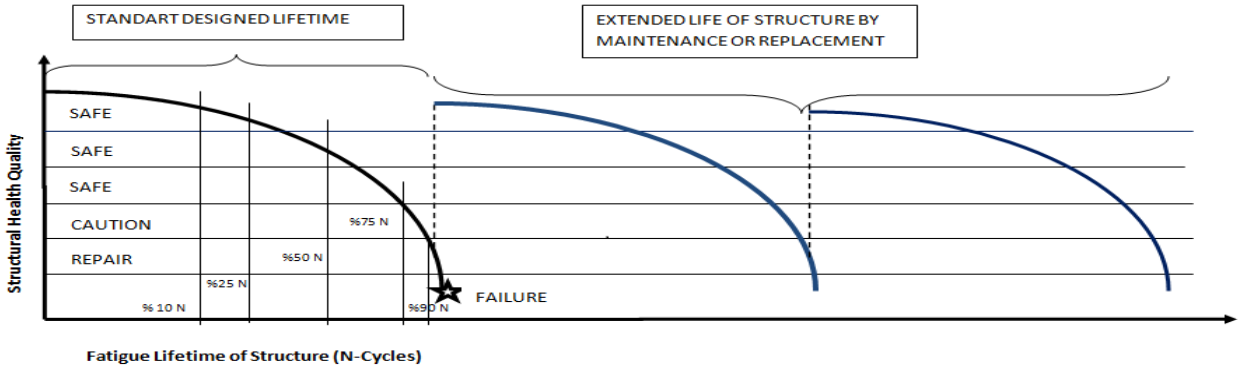
h) The part material properties

i) The part redesigns needs and design modification or revision

k) The part connection properties (rivet, welded etc...)

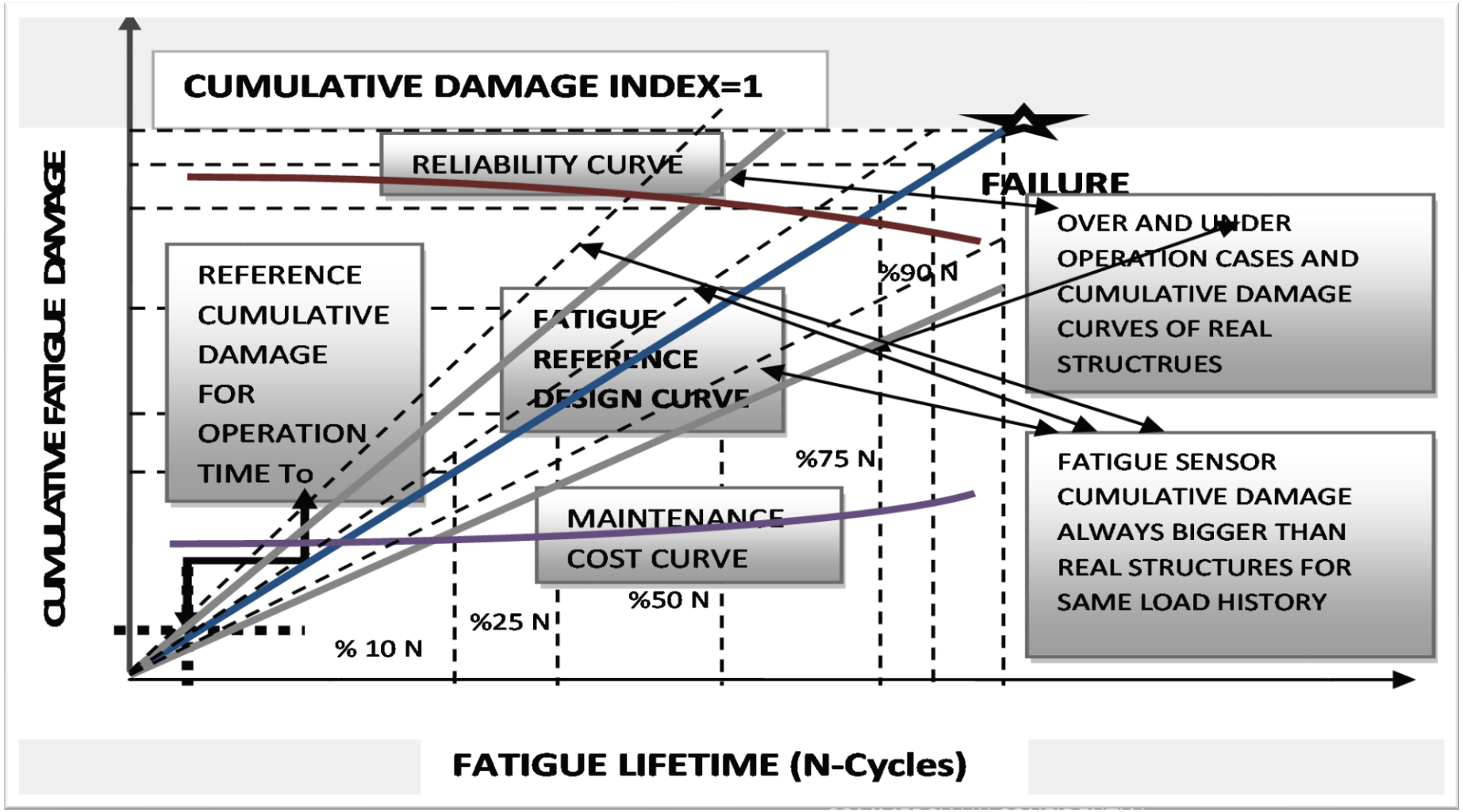
A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (HEALTH QUALITY AND LIFE EXTENSION)



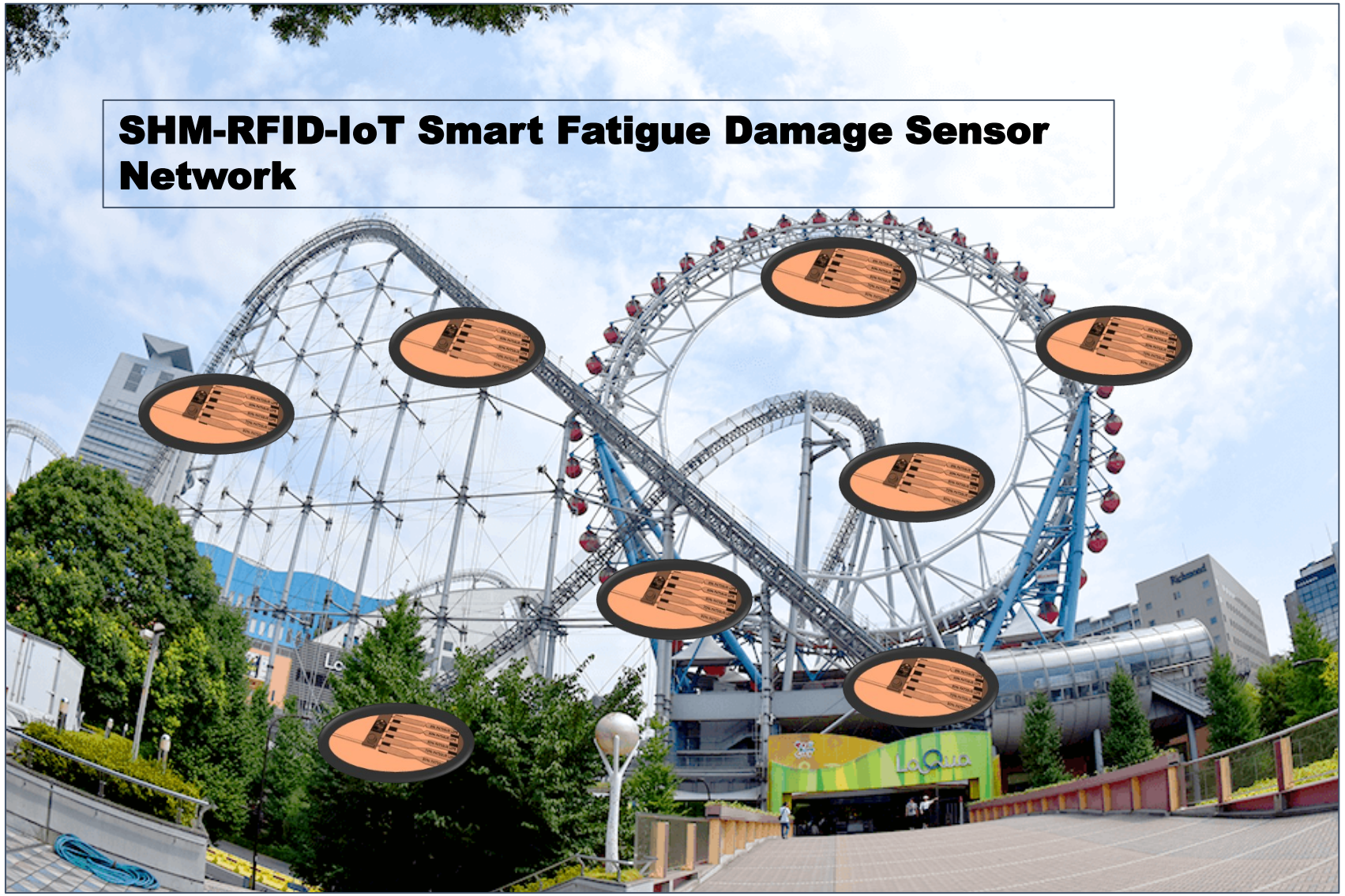


- **The required maintenance decisions and the health state of critical parts of structures are given according to the RFID Fatigue Sensor Network data.**
- **The RFID Fatigue Sensor network information is mandating, the time of the fatigue damaged parts or locations should be repaired or replaced.**
- **Therefore, the proposed RFID Fatigue Sensor based Intelligent Predictive-Condition Based Maintenance Model is very efficient and effective strategic system since it increases service life and reliability and reduces maintenance and operations expenses.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (CUMULATIVE DAMAGE MODEL)



The proposed RFID Sensor Based Structural Health Monitoring and Maintenance Strategy are based on the periodic or real-time sensor information to optimize maintenance resources., INCREASES RELIABILITY, AVALIBILITY, SAFETY, AND EXTENT THE SERVICE LIFE OF STRUCTURES


SHM-RFID-IoT Smart Fatigue Damage Sensor Network