茨城大学重点研究

「知的で持続可能な社会基盤および防災セキュリティ技術研究創出事業」

茨城大学工学部附属
防災セキュリティ技術教育研究センター

２０１６年度
報告書

茨城大学重点研究プロジェクト
「知的で持続可能な社会基盤および防災セキュリティ技術創出事業」

平成28年度報告書刊行にあたって

プロジェクト代表　　呉　智深

本研究課題は，平成23年4月に課題募集プロポーザルとその審査により茨城大学重点研究課題として認定され，工学部，教育学部および茨城大学センター教員から構成される異分野研究者の集う場として活動が始まりました．本年度は活動 5 年目を迎えることとなりました．

この報告書では，学術誌論文をはじめとする研究成果に加えて，参加メンバーの学術企画の開催や参加，受賞例についても整理しましたが，「防災セキュリティ技術」という学際領域に類するテーマが示すように，昨年度に引き続き，多種多様な研究活動とその成果を収めてきたことがわかりました．

2016年を顧みますと，4月14日に熊本県益城町で最大震度7の地震が発生し，また，同月16日には同じ熊本地方を最大震度7.3の地震が発生した．季節が過ぎ，夏になると，台風がかつて無い移動経路を示し，3つの台風が北海道に上陸，地すべり被害が野菜等農作物に甚大な被害が発生しました．このように，我々市民生活が営まれる都市域は，予想もしえない甚大な自然災害に見舞われる可能性が示されたと言えます．

このような状況をいかに早く察知し，安全で安心な都市を作ってゆくのか．防災セキュリティ教育研究センターだけではなく，日本の防災研究の永遠の課題なのかもしれません．そのような中ではありますが，本誌では2016年度の我々の取り組みをご報告させて頂きました．類する教育研究を行っている皆様の何らかの参考になれば幸いです．

末筆とはなりますが，茨城大学重点研究課題として採用頂き，茨城大学の代表する研究課題の 1 つとして諸方面の応援と援助を頂きました茨城大学に心から感謝申し上げますとともに，必ずしも十分でなかった研究交流にも関わらず，本誌に示す多大なる研究成果を上げている参加メンバーに心から敬意と謝意を表します．

今後の研究活動への努力をお約束し，関連する皆様に感謝を申し上げますとともに，ここに平成28年度の研究成果を報告させて頂きます．

平成29年3月吉日
プロジェクト代表　　呉　智深

茨城大学工学部附属防災セキュリティ技術教育研究センター　（2016年度）
プロジェクト参加教員

呉　智深	（工学部都市システム工学科・教授・センター長）
齋藤　修	（防災セキュリティ教育研究センター・特命教授・副センター長）
鎌田　賢	（工学部情報工学科・教授・副センター長）
桑原　祐史	（広域水圏環境科学教育研究センター・教授・センター幹事）
沼尾　達弥	（工学部都市システム工学科・教授）
今井　洋	（工学部電気電子工学科・教授）
原田　隆郎	（工学部都市システム工学科・准教授）
横田　浩久	（工学部電気電子工学科・准教授）
湊　淳	（理工学研究科・教授）
武田　茂樹	（工学部メディア通信工学科・教授）
澁澤　進	（工学部情報工学科・教授）
羽渕　裕真	（工学部情報工学科・教授）
外岡　秀行	（工学部情報工学科・教授）
車谷　麻緒	（工学部都市システム工学科・准教授）
石田　智行	（工学部情報工学科・助教）

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2. 研究報告

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Advancement of long-gauge carbon fiber line sensors for strain measurements in structures,
Journal of Intelligent Material Systems and Structures,
1045389X16665974 (2016-8).

－5－

Hiroshi Noguchi, Yasuhiro Ohtaki and Masaru Kamada,
A university information system made robust against natural disasters by taking advantage of remotely distributed campuses,
International Journal of Space-Based and Situated Computing, 6(3), 147-154 (2016-11).

－15－

3.プロジェクト業績

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1.活動概要

防災セキュリティ教育研究センター　平成28年度活動計画・実施結果調書

１．技術・研究開発分野

担当者氏名：呉　智深	Email：zhishen.wu.prof@vc.ibaraki.ac.jp

・計画名：社会基盤を対象とした維持管理および防災/減災へ向けたセンサ技術・空間情報応用研究

・システムとしての防災・減災技術の確立検討（企業・自治体・学術連携）
実施予定時期：平成28年4月1日～平成29年3月31日

１．実施内容：
- ・センサ技術の開発
  光ファイバセンサ・カーボンファイバセンサ・RFIDタグ・UAV・防災/気象用センサ
  ICタグ（水位・加速度・傾斜・降雨・大気関連）
- ・センサデータの安定した通信/解析技術の開発と省電力化推進
  マルチホップ通信による耐災害メッセージングシステム
- ・センサ技術の現地実証の推進と課題抽出
  老朽化したインフラ構造物の災害リスクを考慮した維持管理計画（継続課題）

・アウトリーチとしての防災・減災、それらを含む環境教育の実施

・地元企業・学校等との学術連携実現

・他大学・企業・自治体連携での研究資金獲得

・自治体との各種連絡会議推進（茨城県・日立市・ひたちなか市等）

・国際共同研究を実施（アメリカ、英国、イタリア、中国、韓国等）

・大型プロジェクトを申請

２．実施体制（注：外部の人も含む）
責任者：呉　智深（センター長）
メンバ：齋藤　修，鎌田　賢，沼尾　達弥，今井　洋，羽淵　裕真，渋沢　進，湊　淳，横田　浩久，原田　隆郎，武田　茂樹，外岡　秀行，桑原　祐史，車谷　麻緒，石田智行
（茨城高専・東北大学・東京大学・青山学院大学の教員の正式参加を調整中）

３．実施における課題：　・・・調整が必要な事項、予算計画など。ない場合は、特になしとする。
特になし.

４．実施結果（年度末に記載）

（結果）　現在の記述は途中経過なので年度末状況を書く必要あり。
・茨城県・水戸市連携による、内水氾濫監視システムの実証実験推進（H29年2月より開始）
・茨城県との連携によるUAVのダム長寿命化への応用検討（H27年7月以降に実施）
・茨城県との連携による常陸大宮、引田橋における加速度センサ設置による橋梁長寿命化対応実証実験（H26年6月より継続中）
・株式会社　KSK　構造診断研究所との連携による新潟県、国道18号妙高大橋における光ファイバセンサ設置による橋梁健全性評価手法の実証実験（H287年11月より実施）
・株式会社　KSK　構造診断研究所との連携による川根大橋におけるカーボンファイバセンサ設置による橋梁振動モニタリング実証実験（H28年12月より実施）
・中国の蘇通長江大橋（橋梁管理局と協力）でのインフラ構造物の早期損傷検知実験（H28年11月より実施）

青山学院大学：UAV 飛行におけるプロトコル確立研究連携
東京大学・長岡技術大学：橋梁長寿命化についての情報交換会

ひたちなか市立外野小学校・前渡小学校での環境・情報特別授業実施（H27 年 9 月）

宮城県名取市閖上地区の UAV による震災被害地アーカイブ映像撮影　宮城教育大学との連携
宮城県女川町・石巻市連携による地盤沈下調査（来年度継続）・UAV による震災アーカイブ映像撮影

日本地球惑星連合(JPGU)2015：セッション「UAV が拓く新しい世界」コンビーナとして UAV の活用を推進。

茨城県生活環境部・土木学会茨城支部・㈱新星コンサルタント等において UAV 操作指導・安全教育を実施。

常総市水害（９月１０日）の UAV による調査・記録・分析に協力（国交省委託事業の一環）

（課題）
少々，計画したイベントが多いため，絞り込む事も重要と考える.

６. その他（参考資料、報告書など）

（注）複数の計画がある場合は、必要に応じて欄を追加する。

２．人材育成

担当者氏名：呉　智深	Email： zhishen.wu.prof@vc.ibaraki.ac.jp

１． 計画名・実施予定時期

計画名：「社会基盤を対象とした維持管理」に関する授業の学部～社会人への展開
実施予定時期：平成 28 年 4 月 1 日～平成 29 年 3 月 31 日

２． 実施内容：

下記の学内授業実施および学生国際会議企画を行い、研究で得た最新情報を学部学生へフィードバックし、また、社会人ドクターの教育を通じて高度化する.

①学部学生に対する教育
　通信理論，ソフトウェア実現，空間情報工学

②大学院博士前期課程学生に対する教育
　構造物の数値解析法，衛星画像および地理情報の解析法，社会基盤情報処理特論

③社会人（専門技術者向）に対する教育
　土木学会茨城会で行っているイブニングセミナ（地域の技術者対象）に防災・センシング関連で講座を出す

④その他：小中高校への環境。防災教育の提供

３． 実施体制（注：外部の人も含む）

責任者：呉　智深（センター長）
メンバ：鎌田　賢，齋藤　修，沼尾　達弥，今井　洋，羽淵　裕真，渋沢　進，湊　淳，桑原　祐史，横田　浩久，原田　隆郎，武田　茂樹，外岡　秀行，車谷　麻緒，石田　智行

４． 実施における課題：　・・・調整が必要な事項、予算計画など。ない場合は、特になしとする。

特になし

５． 実施結果（年度末に記載）

（結果）

現在の記述は途中経過なので年度末状況を書く必要あり。

・茨城県「いばらき近未来実証推進事業」プロジェクト推進委員会委員（アドバイザー）として、UAV を含むロボット実証試験に安全管理・実証方法についてアドバイスを行っている（齋藤、桑原、鎌田）。

（課題）

特になし

６．その他（参考資料、報告書など）

３．資金獲得

担当者氏名：呉　智深	Email：zhishen.wu.prof@vc.ibaraki.ac.jp

１．計画名・実施予定時期

- 計画名：大型プロジェクトの獲得
- 実施予定時期：平成 27 年 4 月 1 日～平成 28 年 3 月 31 日

２．実施内容：

科研費はセンターメンバー個々人がチャレンジすることとし，それ以外の大型プロジェクト（国土交通省，経済産業省，総務省）に，共同研究等で関係のある産官学学外機関との連携を取り，チャレンジする．
昨年度に不採択となった概算要求書をベースとして生かす。

３．実施体制（注：外部の人も含む）

責任者：呉　智深（センター長）
メンバ：鎌田　賢，齋藤　修，沼尾　達弥，今井　洋，羽渕　裕真，渋沢　進，湊　淳，桑原　祐史，
横田　浩久，原田　隆郎，武田　茂樹，外岡　秀行，車谷　麻緒，石田　智行

４．実施における課題：・・・調整が必要な事項、予算計画など。ない場合は、特になしとする。

大型プロジェクトの申請に関する作業時間をより確保する必要がある。

５．実施結果（年度末に記載）

（結果）

現在の記述は途中経過なので年度末状況を書く必要あり。・平成 26 年度募集 SCAT 研究費助成獲得　青山学院大学戸辺教授との連名「複数異種 UAV 間協調動作プロトコルの開発と広域環境観測への応用」
複数の UAV を協調動作させる。防災への応用が期待できる。（H27 年度から 3 年）
また，年度末に小額の外部資金による成果を重ねることにより，NEC との大型共同研究に発展し実現した．
（課題）

特になし

６．その他（参考資料、報告書など）

2.研究報告

（H28 年度参加教員発表の代表的な学術論文集）

Journal of
Intelligent Material
Systems and Structures

Original Article

Advancement of long-gauge carbon fiber line sensors for strain measurements in structures

Journal of Intelligent Material Systems and Structures
1–10
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sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/1045389X16665974
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SAGE

Mohamed A Saifeldeen[1], Nariman Fouad[1], Huang Huang[2] and Zhishen Wu[1]

Abstract

This article proposes a new technique that advances long-gauge carbon fiber line sensor technology, with and without post-tensioning of the sensor, to measure changes in strain levels in structural areas. Carbon fiber line sensors were fabricated to produce a slim high-strength sensor with a diameter of less than 1.4 mm using a carbon fiber tow with a width of 6 mm. A theoretical analysis of these sensors as well as several series of experiments was conducted to investigate the effect of fiber arrangement on the error compensation of the carbon fiber line sensors. The results revealed that using two sets of carbon fiber line sensors, one as an active sensor and the other to compensate the errors of the first, is an effective method when both sensors have a convergent fiber arrangement and change in resistance. A post-tensioning method was implemented to enhance the overall behavior of the sensor. The results showed that the post-tensioning method yields significant improvement in the linearity and cyclic ability up to 6000 microstrains and reduces the fluctuation errors in the change in resistance from ±0.031% to ±0.007%. Finally, the possibility of repairing damaged carbon fiber line sensors is also discussed.

Keywords

Carbon fibers, sensors, resistivity, post-tension, strain measurements

Introduction

In recent decades, carbon fiber–reinforced plastics (CFRP) have been widely investigated and applied in the aerospace, civil engineering, and auto industries because of their superior strength, stiffness-to-weight ratios, low density, long-term durability, and high resistance to chemical corrosion. In addition to these advantageous properties, another important characteristic of CFRPs is their favorable electrical conductivity and piezoresistivity (Schueler et al., 2001; Wu and Yang, 2006; Yang et al., 2006). In general, the resistivity of CFRPs increases linearly with applied tension and decreases linearly under compression, demonstrating piezoresistive effects. These electrical properties produce resistance variations in CFRPs undergoing changes in their mechanical, chemical, and thermal environments and thus render CFRPs potentially applicable as sensors of strain, stress, bio-feedback, damage, chemical exposure, and temperature (Ogi and Takao, 2005; Park et al., 2005; Shui and Chung, 1996; Wang and Chung, 2006; Wu et al., 2005, 2007).

Sensors can be separated into two types based on their gauge length: point sensors and long-gauge sensors. Point sensors are typically mounted near key parameters, as they have high sensitivity and precision. However, these sensors are expensive and are not suitable for detecting parameters in a large area or global sensing. In contrast, long-gauge sensors can be used for global sensing, which is useful for providing a comprehensive evaluation of the integrity of a structure (Huang and Wu, 2010).

Huang et al. (2010, 2012) studied the electrical sensing properties of CFRP strips to produce a CFRP strip long-gauge sensor for measuring low strain levels. It was found that the effective sensing behavior of a CFRP strip is related to its effective gauge length, and the transverse connection in a CFRP strip affects the

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[1] Department of Urban and Civil Engineering, Ibaraki University, Hitachi, Japan
[2] Key Laboratory of Concrete and Prestressed Concrete Structure of the Ministry of Education, Southeast University, Nanjing, China

Corresponding author:
Zhishen Wu, Department of Urban and Civil Engineering, Ibaraki University, Hitachi 316-8511, Japan.
Email: zhishen.wu.prof@vc.ibaraki.ac.jp

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linear strain response, especially when sensing is in a low strain range. The strain response properties of CFRP strips became more linear when the width-to-length ratio decreased. Moreover, when the gauge length of a CFRP strip was 500 mm or longer, its strain response exhibited a good linear relationship with the applied strain even at the low strain level of 200 microstrains. The strain response of a 500-mm-long CFRP strip maintained stable linearity throughout exposure to long-term cyclic tensile strain.

The change in resistance $\Delta R/R$ of a carbon fiber (CF) sensor is inversely proportional to the change in temperature because of the negative temperature resistivity of micro-CF. The measured signal from the CF sensors is related to the change in strain on the structural object but is also impacted by undesired effects from conditions such as temperature and humidity. CFs used continuously as the strain sensing elements in CF sensors clearly exhibit thermoelectric effects, reducing the reliability of the results calculated from these measurement signals (Huang et al., 2011; Huang and Wu, 2010). For carbon fiber line (CFL) sensors, the relationship between the change in resistance ($\Delta R/R$), the applied strain ε, and the external errors (e) can be expressed as follows, where G_f is the gauge factor

$$\frac{\Delta R}{R} = G_f \times (\varepsilon + e) \tag{1}$$

This problem of dual sensitivity to strain and other effects has plagued CFL sensors, and compensation for this error is necessary to advance a CFL sensor that yields effective and reliable strain measurements. Selecting and applying an appropriate compensating CF sensor is crucial to achieve improvement in the accuracy of results. The compensation sensor must be fabricated from the same material and have the same physical properties and gauge length as the active sensor and must only be subjected to interference effects and never to any quantity of applied strain (ε).

Huang and Wu (2012) also developed a signal processing method used to treat the structural strain responses of long-gauge CF sensors for static and dynamic strain measurements. This static denoising method is based on measuring the error range of CF sensors, as determined over long-term continuous loading and unloading experiments. For the experiment involving one-measure-time each second, the influence of noise on CF sensors followed a normal distribution, with a standard deviation of ±50 microstrains. For the experiment involving 25-measure-time each second, the signals were concentrated in a smaller range, and the probability density showed a clear increase. For signal selection based on multiple measuring times, the measured error range of CF sensors was consolidated from ±50 to ±10 microstrains.

This article presents a new approach for obtaining a long-gauge CFL sensor. The theoretical and experimental investigations discussed here clarified the effect of fiber arrangement on the error compensation of CFL sensors. Furthermore, a post-tensioning method was implemented to enhance the sensing behavior and cyclic ability of the CFL sensor under conditions of low and high strain. Finally, the possibility of repairing damaged CFL sensors is also discussed.

Theoretical background on the measuring circuit

The principle behind the operation of CFL sensors is based on establishing a relationship between the change in resistance $\Delta R/R$ and the strain ε. The resistance of a CFL sensor can be expressed as

$$R = \rho \times \left(\frac{L}{A}\right) \tag{2}$$

where ρ is the resistivity, L is the effective gauge length of the sensor, and A is the cross-sectional area of the sensor. $\Delta R/R$ can be expressed as

$$\frac{\Delta R}{R} = f\left(\frac{\Delta\rho}{\rho}, \frac{\Delta L}{L}, \frac{\Delta A}{A}\right) \tag{3}$$

According to the piezoresistive effect of semiconductor materials, the change in resistivity has a much greater effect than simple changes in geometry on $\Delta R/R$ (Huang and Wu, 2010). The $\Delta R/R$ of the sensor can therefore be expressed as

$$\frac{\Delta R}{R} \cong \frac{\Delta\rho}{\rho} \tag{4}$$

Equation (4) represents the ideal condition, in which all the micro-CFs are ideally aligned and separated by epoxy resin, and the transverse electrical contact's contribution to the sensor's conductivity can be neglected. Then, the electrical resistance can be obtained by the parallel circuit approach from (Yang and Wu, 2003)

$$R_0 = \frac{R_f}{n_f} \tag{5}$$

where R_0 is the initial resistance of the CFL sensor, R_f is the resistance of one microfiber, and n_f is the number of fibers in the sensor. In fact, owing to manufacturing defects inherent in CFL production, the arrangement of the microfibers in each sensor is different. To reflect practical conditions, $\Delta R/R$ can be written as

$$\frac{\Delta R}{R} = (1-\eta)\frac{\Delta\rho}{\rho} \tag{6}$$

where η is a coefficient that reflects the transverse electrical contact's contribution to the sensor's

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Table 1. Properties of carbon fiber tow and epoxy resin.

Material	Thickness (mm)	Tensile strength	Tensile modulus (GPa)	Tensile elongation (%)	Volume resistivity (Ω cm)
Carbon fiber T700SC	0.136	4.9 GPa	230	2.1	1.6×10^{-3}
Epoxy resin FR-E3P		51.9 MPa	3.43	1.513	1010–1020

conductivity. Thus, for any given strain level, ΔR/R differs from one sensor to another, as does the gauge factor.

By applying the Wheatstone bridge circuit to measure the total output signal of the active and compensation sensors, the change in resistance can be expressed as

$$\frac{\Delta R}{R} = G_{fw} \times (\varepsilon_w + e_w) - G_{fc}e_c \qquad (7)$$

where G_{fw}, ε_w, and e_w are the gauge factor, applied strain, and external effects errors of the active sensor, respectively; and G_{fc} and e_c are the gauge factor and external effect errors of the compensation sensor, respectively. Under ideal conditions, when (1) the compensation sensor is subjected to only external effects, (2) both sensors have the same gauge factor G_f, and (3) both sensors undergo the same external effects, the errors due to external effects will be effectively eliminated, and the output signal will be related to the applied strain only.

As described in this section, the two sensors will not be identical because of differences in their fiber arrangements, resulting in differences in their ΔR/R and gauge factors. Thus, errors caused by external effects will not be entirely removed; however, these errors can be reduced by choosing a compensation sensor with a gauge factor that converges on the gauge factor of the active sensor.

Experimental procedure and materials

The CF's transverse connection, or tow, consists of numerous continuous microcarbon fibers. Each fiber can be considered as a sensing cell, such that the CF sensor's output signal is the integrated response from all of the sensing cells. Under ideal conditions, a CF tow can be considered a parallel circuit that is composed of large numbers of micro-CFs. Under actual conditions, the microfibers are not completely straightened or arranged in parallel due to manufacturing defects, such as misalignment and breakage of fibers. Because the fiber distribution in this transverse connection introduces variability, the CFs of the samples in this study were pre-tensioned for 24 h under 500 microstrains to make the fibers as straight as possible.

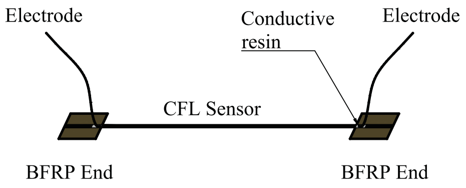

Figure 1. Schematic of the CFL sensor in its processing fixture.

Subsequently, to produce a CFL sensor with a gauge length of 500 mm, both ends were fully filled with conductive resins to improve the electrical contacts to each of the CFs in the cross section and to avoid the errors from contact resistance between CFs and the electrodes (Park et al., 2005), and then, the electrodes were connected to the conductive resin at both ends of the CFs with tin solder and copper cables. The CFs were then impregnated with epoxy resins and collected together manually to form a CFL sensor with a diameter of approximately 1.4 mm. Furthermore, the ends of the fixture used to hold the CFs in place were made of basalt fiber–reinforced polymer (BFRP) sheets and were bigger than the ends of the measurement sensor, thus providing enough bonding force to form the CFL sensor. The impregnated CFL sensor was cured at a temperature of approximately 45°C for 3 days, maintaining the sensor under tension until it was completely hardened. Finally, the tensile stress was released and the CFL sensor was ready to be installed at its measurement location, as shown in Figure 1. For all of the experiments in this study, the CFL sensors were installed on homogenous elastic glass fiber plates.

The CF tow used in this study was T700SC, produced by Toray Industries, Inc. The epoxy resin used was FR-E3P, produced by Nippon Steel Composite Co., Ltd, a bonding material approved by the Japan Society of Civil Engineers. The properties of these materials are shown in Table 1.

To measure and monitor electrical strain, a CFL sensor must be connected to an electrical circuit that is capable of measuring changes in resistance corresponding to strain. A data measurement system was constructed with a Wheatstone measuring bridge connecting the active and compensation sensors, as shown in Figure 2.

Discussions

The effect of gauge factor on the compensation method

To study the effect of the change in the gauge factor on the compensation method, three sensors CFL_1, CFL_2,

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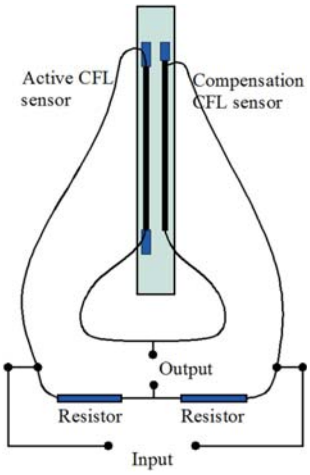

Figure 2. Connection of the active and compensation sensors with a Wheatstone bridge.

and CFL_3 were tensioned individually under 750 microstrains, and their measured ΔR/R signals were compared with the strain gauge as a reference strain. Figure 3 shows the behavior of the three sensors tested, and it is clear from the results that CFL_1 and CFL_2 had convergent ΔR/R, whereas ΔR/R for both of these sensors diverged from that of CFL_3.

In these experiments, the same CFL_1 was tested three times under a cyclic loading–unloading tension test from 0 to 750 με with a loading rate of 1 kN/min (strain rate of 185 με/min) under a stable laboratory conditions (18°C–20°C and 25%–30% relative humidity). The first test (group S_1) did not include a compensation sensor. For the second and third tests (groups S_2 and S_3), the same sensor used in group S_1 was connected with CFL_2 and CFL_3 as compensation sensors, respectively.

From Figure 4(a) to (d), the cyclic behavior of CFL_1 exhibited some error, which can be considered to be due to the external effects discussed in section "Introduction." To reduce these errors, a compensation sensor was connected with the active sensor in groups S_2 and S_3. Strain signal measurements of group S_2 showed good stability, and the ΔR/R error was reduced from 0.022% to 0.007%, a reduction percentage of 68.2%. On the other hand, for group S_3, the ΔR/R error was reduced by a small value: from 0.022% to 0.015%, a reduction percentage of 31.8%. From the comparison of the three groups S_1, S_2, and S_3 shown in Figure 4(d), it can be concluded that use of a compensation sensor with a gauge factor closer to that of the active sensor can reduce the ΔR/R error significantly. These results are consistent with the theoretical approach in section "Theoretical background on the measuring circuit."

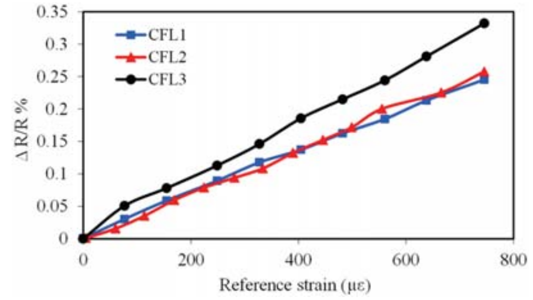

Figure 3. ΔR/R of CFL_1, CFL_2, and CFL_3 relative to the reference strain.

Performance of CFL sensors under different strain levels

The behavior of group S_2 was studied under different strains to define the sensor's error in the full range of strain levels. Thus, a cyclic tension test was applied in seven strain ranges to determine the cyclic behavior of the sensor. The tension loading–unloading cycle was repeated 30 times under each strain level: 300, 500, 750, 1000, 2000, 3000, and 4000 microstrains. All ranges were tested under approximately the same environmental conditions and load rating.

Figure 5(a) shows the relationship between the average $\Delta R/R_s$ over 30 loading cycles for each of the strain levels, relative to the reference strain. It is clear from Figure 5 that under higher applied strain, the measured signal exhibits poor linearity, showing instead a curvature that increases as the strain reaches maximum levels. Furthermore, the slope of the curvature increases with the increase in the strain value, and then, it gradually stabilizes in strain levels higher than 3000 microstrains, and it seems to be constant which has approximately average value of about 0.00049. To examine the relationship between signal fluctuation and maximum strain level from low to high strain levels, Figure 5(b) shows the distribution of the measured signal's fluctuation through the 30 loading–unloading cycles for each of the seven experimental strain ranges. The errors of the signals under the different strain levels follow a normal distribution curve; this normal distribution lies entirely within the range of random extended signal fluctuation. Figure 5 shows that there is no significant change in signal fluctuation for the first three strain levels (300, 500, and 750 microstrains); the errors then increase with increasing strain until an upper limit of 3000 microstrains, after which the error appears to stay approximately constant. Table 2 illustrates the fitted equations and errors at each of the strain ranges; the errors were calculated to represent a 95% of the normal distribution, as calculated by standard deviations.

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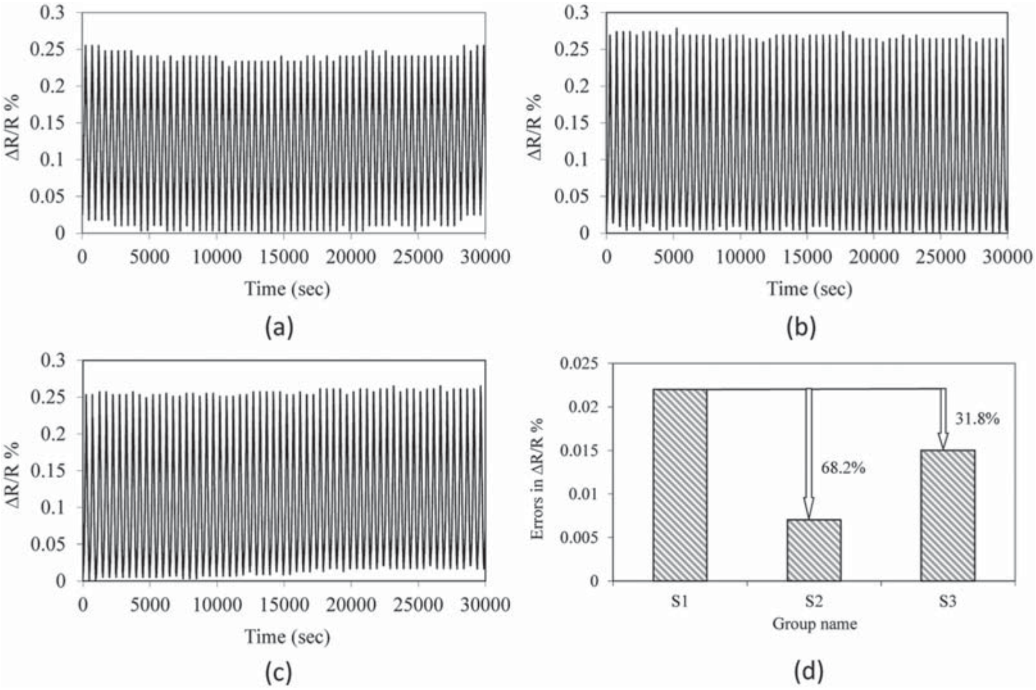

Figure 4. ΔR/R of CFLs under conditions of cyclic loading: (a) for group S_1, (b) for group S_2, (c) for group S_3, and (d) the errors in ΔR/R for each group.

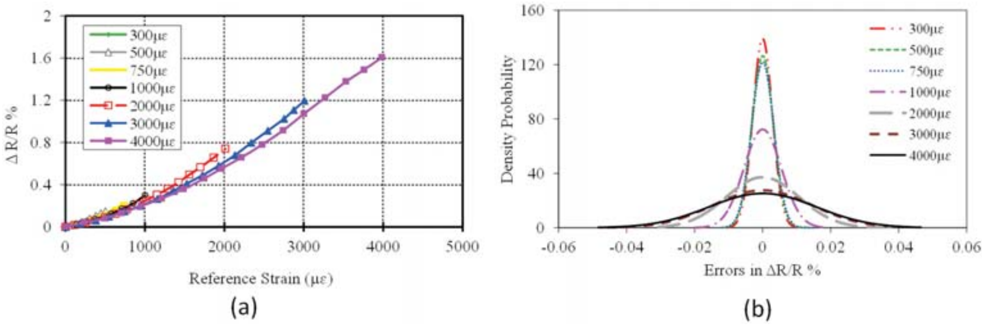

Figure 5. (a) The CFL sensor's average ΔR/R over 30 loading cycles from 300 to 4000 $\mu\varepsilon$ and (b) the errors in ΔR/R of the CFL sensor under different strain levels.

During the fabrication of the CFL sensors, the CFs were pre-tensioned so that all of the microfibers were as straight as possible; in fact, however, not all of the microfibers could be completely straightened and would therefore not be pre-tensioned. As a result, at the beginning of the tests, the tension force F was not evenly distributed to all of the microfibers. Each fiber received a different magnitude of the force (F_1, F_2, …, F_n), and some fibers did not receive any force ($F = 0$) because of the winding of the fibers upon themselves. As the force of applied tension increased, some of the wound fibers also began to receive force, becoming active microfibers. Thus, the gauge factor of the active sensor differed from the compensation sensor, causing additional errors in the measured signal. These errors increased with increased applied strain, until reaching a limit at which the most of microfibers were active fibers. The incremental increase in error therefore has an upper limit above which it will not increase.

Regarding the curvature trend that appeared in the measured ΔR/R of the signals under high levels of applied strain, this phenomenon is considered to be caused by creep deformation from the resin, relaxation of the polymer matrix resin which is a viscoelastic material, and a slight elongation of the microfibers themselves. Inasmuch as the sensor was fixed from both ends on the glass fiber test plate, the slight elongation that occurred prevented full tensioning of the sensor on

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Table 2. The results of tests of the CFL sensor under different strain levels.

Maximum strain (με)	Maximum ΔR/R (%)	Fitted equations	Errors ΔR/R (%)
300	0.091	$\Delta R/R = 0.0003 \times \varepsilon - 0.0065$	±0.0057
500	0.152	$\Delta R/R = 0.0003 \times \varepsilon - 0.0076$	±0.0063
750	0.224	$\Delta R/R = 0.0003 \times \varepsilon - 0.0124$	±0.0072
1000	0.33	$\Delta R/R = 0.0004 \times \varepsilon - 0.0007$	±0.011
2000	0.75	$\Delta R/R = 0.0004 \times \varepsilon - 0.0782$	±0.0214
3000	1.195	$\Delta R/R = 0.0004 \times \varepsilon - 0.126$	±0.0289
4000	1.61	$\Delta R/R = 0.0004 \times \varepsilon - 0.1693$	±0.031

CFL: carbon fiber line.

the plate, resulting in poor sensor sensitivity to low strains.

Post-tensioning method to enhance the behavior of CFL sensor

The tensioned fibers of fiber-reinforced plastic (FRP) composites did not exhibit creep, whereas significant creep occurred in the resin; therefore, the creep strain in the entire FRP material can be very limited if the fibers in the FRP are sufficiently straight (Everett, 1996). However, limitations of the production technology result in unevenness from fiber movements, such as local bending and skewedness, which are unavoidable. The elimination of creep deformation in the resin would allow stress to be uniformly transferred through the resin (Soudki, 1998). Therefore, it was considered that the unevenness of the fibers could be adjusted by post-tensioning along the axial direction of the longitudinal fibers. The resin in the CFL sensor continues to undergo creep deformation when it is subjected to a sustained load, allowing the possibility that the fibers could interact in the resin. During this post-tensioning process, the fibers tend to straighten because of resin creep, and their previously occurring unevenness can be adjusted, as shown in Figure 6.

To achieve this purpose, the CFL active and compensation sensors were post-tensioned after hardening using a tensile testing machine under a stress level of 0.60 f_u for 3 h. Subsequently, the sensors were installed on a glass fiber test plate, as before. The results of the post-tensioning test are shown in Figure 7, in which it can be seen that the creep in the CFL sensor increased with increased loading time until 2 h, after which the creep remained constant. Therefore, 2 h of loading eliminated errors from resin creep.

Tests of the sensor under the same seven strain levels were repeated to verify the enhancement percentage of the post-tensioning method. Figure 8 shows the performance of the sensors under the different strain levels, and the high degree of linearity of the post-tensioned CFL sensor is evident from Figure 8 for all strain levels from low to high. In addition to the enhanced linearity, the errors in $\Delta R/R$ were decreased, becoming constant at all strain levels, as apparent from Figure 8 and Table 3.

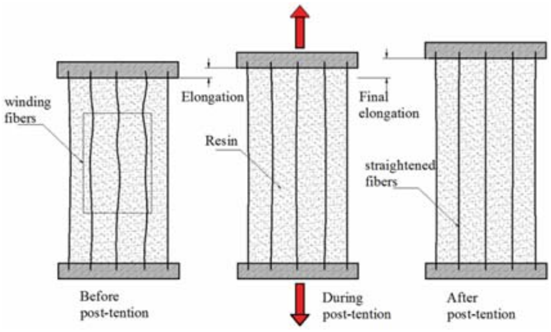

Figure 6. Mechanism of the post-tensioning process.

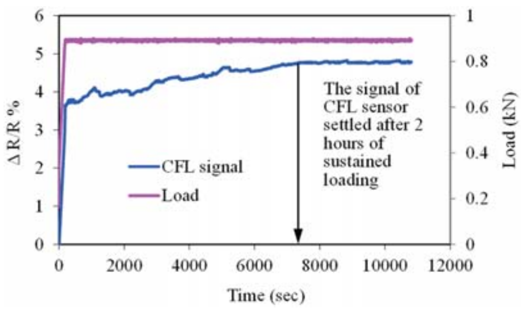

Figure 7. Results of post-tensioning tests of the CFL sensor.

As a result of the post-tensioning of the CFL sensor, most of the microfibers were sufficiently straightened because of resin creep, and the previous unevenness of fibers was adjusted, resulting in a more uniform load carrying capacity. Moreover, the gauge factor of the active and compensation sensors will be constant and stable at any strain level; consequently, the errors in the measured signal can be limited and stabilized. From the fitted equations in Table 3, the gauge factor at any strain level has a constant value of 5, and 95% of the errors are within approximately ±0.007% (approximately ±14 microstrains). Finally, Figure 9 shows a comparison between the errors of the measured signal

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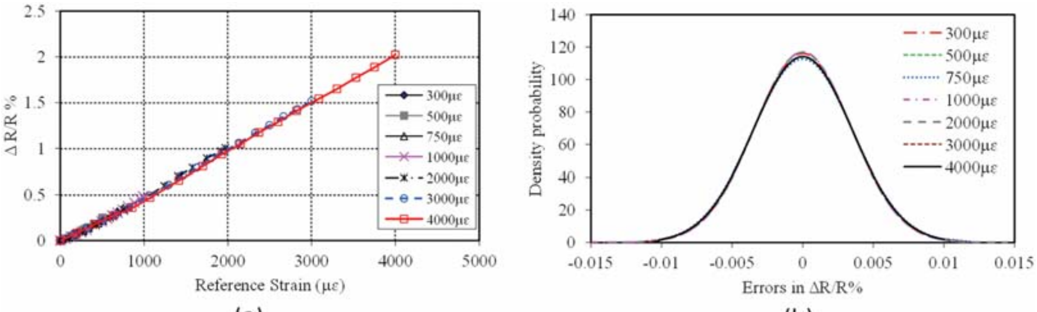
Table 3. Results of tests of the post-tensioned CFL sensor under different strain levels.

Maximum strain (με)	Maximum ΔR/R (%)	Fitted equations	Errors ΔR/R (%)
300	0.152	$\Delta R/R = 0.0005 \times \varepsilon - 0.0092$	±0.0069
500	0.248	$\Delta R/R = 0.0005 \times \varepsilon - 0.0098$	±0.007
750	0.36	$\Delta R/R = 0.0005 \times \varepsilon - 0.0167$	±0.0071
1000	0.484	$\Delta R/R = 0.0005 \times \varepsilon - 0.0271$	±0.0068
2000	1.006	$\Delta R/R = 0.0005 \times \varepsilon - 0.0364$	±0.0068
3000	1.51	$\Delta R/R = 0.0005 \times \varepsilon - 0.0432$	±0.007
4000	2.02	$\Delta R/R = 0.0005 \times \varepsilon - 0.0575$	±0.0072

CFL: carbon fiber line.



(a) (b)

Figure 8. (a) The post-tensioned CFL sensor's average ΔR/R over 30 loading cycles from 300 to 4000 με and (b) fluctuation errors in ΔR/R of the post-tensioned CFL sensor under different strain levels.

of the standard and post-tensioned CFL sensors under each strain level.

The measuring error of a CFL sensor generally includes a systematic error and a random error. The systematic error is a basic measure of sensor performance; on the other hand, the random error is generally caused by unstable external conditions, and it is difficult to forecast but can easily be reduced using the multi-measuring method in Huang and Wu (2012). By increasing the number of measurements taken in 1 s from 1 to 25, the total error can be reduced to ±5 microstrains, as shown in Figure 10.

Efficiency of the post-tensioned CFL sensor under high strains

Two specimens of post-tensioned CFL sensors were utilized to clarify the efficiency of the post-tensioning method in measuring high strain levels and elucidate the effects of post-tensioning on the gauge factor. The first specimen was tested under cyclic loading–unloading tensile strain, after having already been tested up to 4000 microstrains in the investigation discussed in section "Post-tensioning method to enhance the behavior of CFL sensor." The rate of loading increased gradually by increments of 1000 microstrains to evaluate the limits of the sensor's cyclic ability and the linearity of its signals. As is evident from

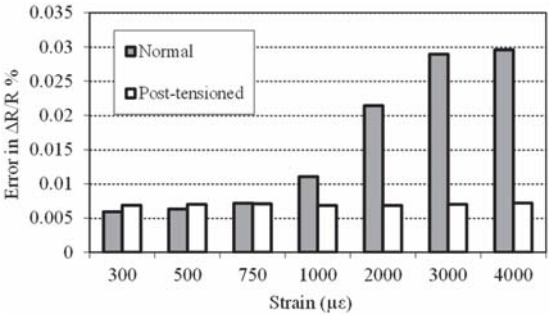


Figure 9. Comparison of the errors in the measured signal of the standard and post-tensioned CFL sensors under each strain level.

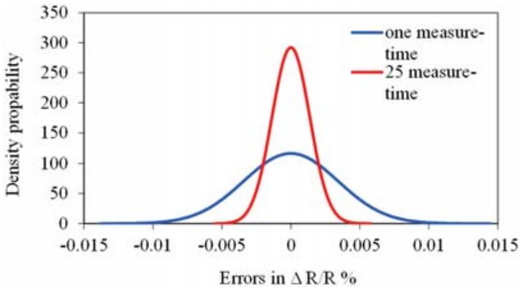


Figure 10. Comparison of the fluctuation errors when measurements are taken from 1 to 25 times a second.

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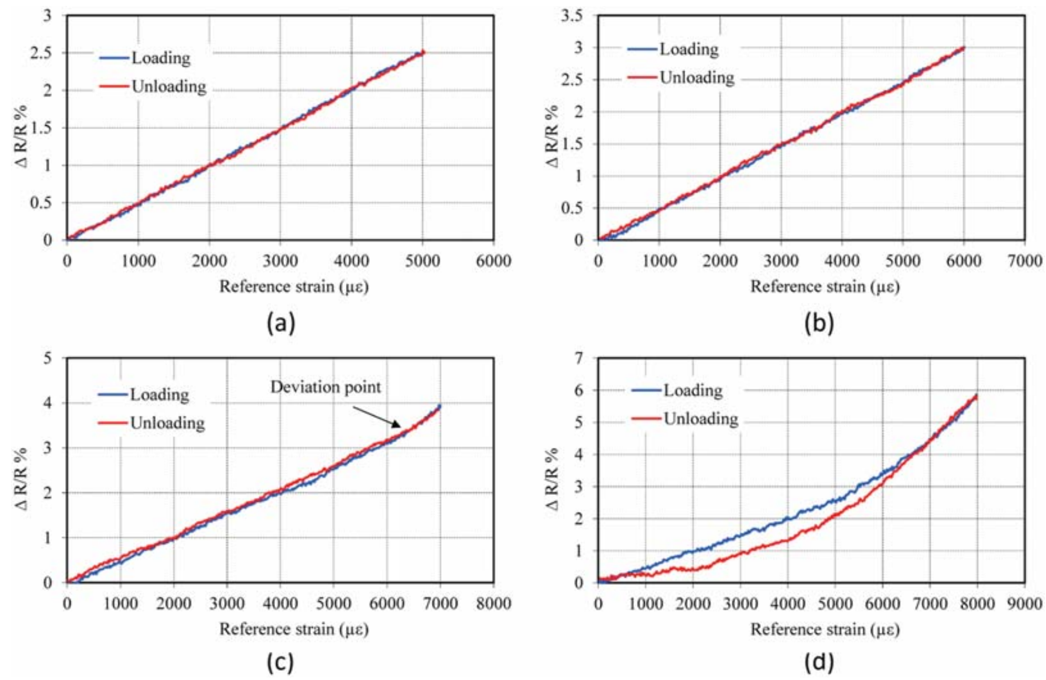

(a) (b) (c) (d)

Figure 11. The post-tensioned CFL sensor's average ΔR/R over 30 loading–unloading cycles under high strains of (a) 5000 με, (b) 6000 με, (c) 7000 με, and (d) 8000 με.

Figures 11(a) to (d) and 12, the post-tensioned CFL sensor functioned well until 6000 microstrains, above which the sensor signal exhibited poor linearity relative to the reference strain, and the error clearly increased at the higher levels. It is evident from Figures 11 and 12 that the loading trend converged with the unloading trend until 6000 microstrains, above which the unloading trend neutralized and began to change its slope. This phenomenon can be considered a result of the initiation of microfracture to some of the microfibers. By means of loading–unloading tension cycles, the damage increases gradually resulting in stiffness reduction and some residual increase in the electrical resistance, which caused a small amount of random variation in the resistivity of the sensor during loading and unloading.

The second post-tensioned specimen was tensioned directly to an adequate strain of approximately 10,000 microstrains to investigate the overall behavior and changes in the gauge factor values relative to the reference strain gauge. The result clarified that the value of the gauge factor deviated substantially between 6000 and 7000 microstrains, as is apparent from Figure 13. The results from this second specimen's limits of linearity and gauge factor are compatible with the first specimen, at 6000 microstrains and 5, respectively.

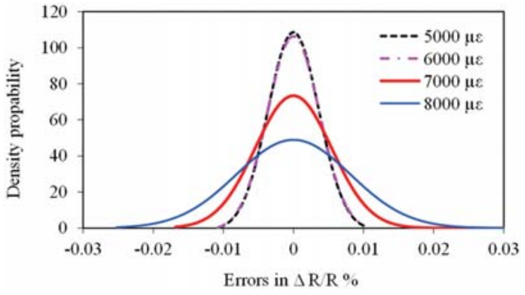

Figure 12. Signal fluctuation errors of the post-tensioned CFL sensor under higher strain levels.

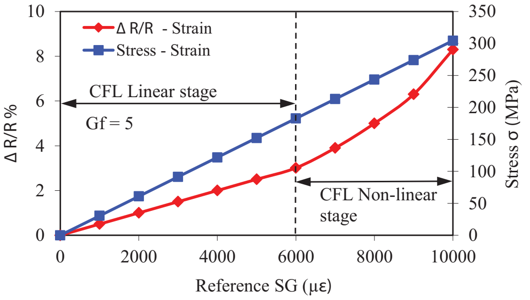

Figure 13. Performance of the post-tensioned CFL sensor up to 10,000 microstrains.

For the second specimen, some cracks and separation between the microfibers occurred when the specimen was loaded with 10,000 microstrains, as shown in Figure 14. This specimen was tested again under 30 cycles of loading under approximately 5000 microstrains, 50% of the maximum strain. Because of the

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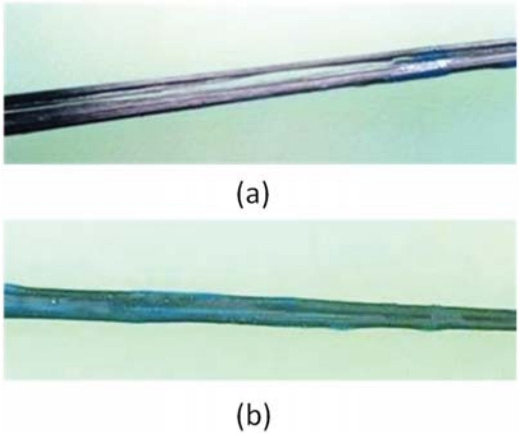

Figure 14. Optical photographs of the CFL sensor (a) after damage under 10,000 microstrains and (b) after repair.

separation between the fibers, the stress transferred into the fibers irregularly, affecting the stability of the measured signal. Therefore, a method of repairing the sensor is needed to control the regularity of stress transferring into the fibers. For this purpose, the sensor was repaired by re-impregnating the collected microfibers with epoxy resin. The cyclic behavior of the repaired sensor was then determined. Figure 15 shows that the signal from the repaired sensor exhibited good linearity until 3000 microstrains, after which the sensor lost stability and linearity and fluctuation errors increased.

Figure 16 shows a comparison of the post-tensioned CFL sensor before and after the repair, demonstrating that the sensor exhibited excellent linearity before any damage but showed poor linearity after damage, relative to the reference strain, with fluctuation errors in ΔR/R increased to a high value of 0.0255%. Figure 16 also shows that the repaired sensor had the same gauge factor as the normal mode of the post-tensioned sensor until 3000 microstrains. Moreover, the errors were reduced to 0.0105%. In general, it can be said that it is possible to repair the CFL sensor if its fibers are micro-damaged by stress or external effects.

Conclusion

This article presents a new technique for measuring strain levels with a CFL sensor. The CFL sensor was fabricated manually to produce a long-gauge line sensor with a small diameter of less than 1.4 mm. The sensing errors of the CFL sensors were studied theoretically

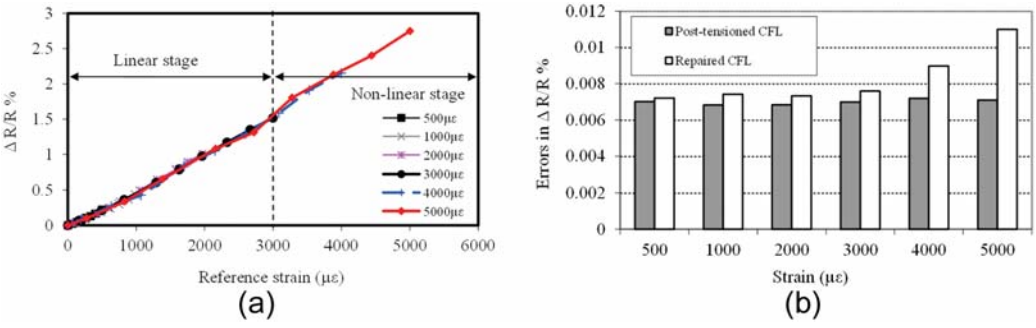

Figure 15. (a) The repaired CFL sensor's average ΔR/R over 30 loading cycles from 500 to 5000 με and (b) error comparison of the post-tensioned CFL sensor before and after the repair under different strain levels.

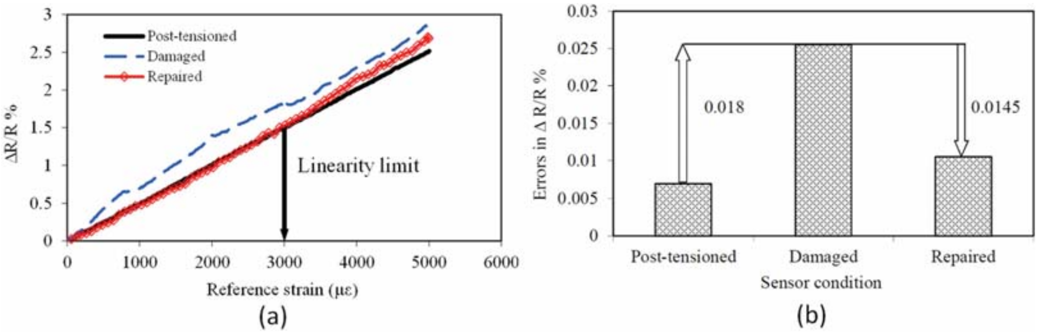

Figure 16. Comparison of the post-tensioned, damaged, and repaired cases of the CFL sensor: (a) average ΔR/R over 30 cyclic loading tests up to 5000 με and (b) signal fluctuation errors in ΔR/R.

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and experimentally. Some important conclusions can be drawn as follows:

1. The output signal of CF sensors needs to be compensated with an associated compensation sensor to reduce the undesired effects from external conditions. It has been demonstrated that a compensation sensor with a fiber arrangement and gauge factor that converges on those of the active sensor effectively reduces error.
2. The CFL sensor signal demonstrates good linearity with the applied strain under low strain levels; however, some curvature appeared and increased under higher strain levels. The signal fluctuation errors increased with increased applied strain levels up to 3000 microstrains, and then, the signal fluctuation error appears to remain constant.
3. A method of post-tensioning to control the initial creep of the CFL sensor was applied by tensioning the CFL sensor for 3 h under sustained stress of 0.60 f_u. The results showed that the post-tensioning method can significantly enhance the linearity of the measured signals and can eliminate or reduce errors.
4. The post-tensioned CFL sensor exhibits a good cyclic ability and stable gauge factor up to 6000 microstrains and can reduce the fluctuation errors in the $\Delta R/R$ from $\pm 0.031\%$ to $\pm 0.007\%$. Beyond 6000 microstrains, the sensor exhibits poor linearity relative to the reference strain.
5. Further results showed that the sensor can be repaired if some damage to the microfibers has occurred; the repaired CFL sensor can be reused for strain measurements up to 3000 microstrains with acceptable errors.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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This is the authors' final submitted version of the paper published by Int. J. of Space-Based and Situated Computing, 2016 Vol.6, No.3, pp.147 - 154. http://dx.doi.org/10.1504/IJSSC.2016.10001161

A university information system made robust against natural disasters by taking advantage of remotely distributed campuses

Hiroshi Noguchi

Center for Information Technology,
Ibaraki University,
Hitachi 316-8511, Japan
Fax: 81-294-38-5158
E-mail: hiroshi.noguchi.daemon@vc.ibaraki.ac.jp

Yasuhiro Ohtaki

Center for Information Technology,
Ibaraki University,
Hitachi 316-8511, Japan
Fax: 81-294-38-5158
E-mail: yasuhiro.ohtaki.lcars@vc.ibaraki.ac.jp

Masaru Kamada*

Department of Computer and Information Sciences
& Center for Information Technology,
Ibaraki University,
Hitachi 316-8511, Japan
Fax: 81-294-38-5158
E-mail: masaru.kamada.snoopy@vc.ibaraki.ac.jp
*Corresponding author

Abstract: We present an information system designed for a university on the basis of its experiences with the 2011 east Japan earthquake. This system has two levels of security: (1) The web site for public relations and the e-mail systems for communications that will work continuously even in the case of commercial power failure. (2) The personal computer systems that will be down during power failure but will restart working without any loss of data as soon as the power supply is back. The former has been implemented by employing a private cloud computing platform and a public one in combination. To the latter, the same cloud-computing approach was not applicable because it causes latency and extra cost of communications in the normal time to keep the frequently accessed data in a cloud storage. Fortunately, this particular university has three campuses so far away that one may be destroyed by a single disaster but the other two will survive. Taking advantage of the remote campuses, we designed and implemented a file storage system that keeps the original copy on-premise in a campus and its backup copy in one of the other two campuses. Its operations have shown that the communication traffic among the campuses increased only by half in order to keep the data safe against natural disasters.

Keywords: disaster robustness; business continuity planning; distributed data backup.

Reference to this paper should be made as follows: Noguchi, H., Ohraki, Y. and Kamada, M. (20??) 'A university information system made robust against natural disasters by taking advantage of remotely distributed campuses', *Int. J. Space-Based and Situated Computing*, Vol. x, No y, pp. aa–bb.

Biographical notes: Hiroshi Noguchi received his bachelor's degree in mathematics from Chuo University in 1986. On finishing his master's degree in economics at the University of Tsukuba, he joined Ibaraki University where he is currently a lecturer with the Center for Information Technology.

Yasuhiro Ohtaki received his bachelor's degree from the University of Tsukuba in 1989, and his Ph.D (in engineering) from the same university in 1994. In the same year, he started working at Ibaraki University where he is currently a lecturer with the Center for Information Technology. His current research interests include applied cryptography and computer forensics.

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Masaru Kamada received his bachelor's (1984) and doctoral (1988) degrees in engineering from the University of Tsukuba and worked for the same university as a faculty member. In 1992, he joined Ibaraki University where he is currently a professor of computer science and the director of the Center for Information Technology. He has been serving *Sampling Theory in Signal and Image Processing* as its secretary since 2003 and he has been an associate editor of the *IEEE Transactions on Industrial Electronics* since 2009. Besides information systems, he is working also on signal and image processing.

1 Introduction

The 2011 east Japan earthquake hit the north east part of Japan on March 11th including the three campuses of Ibaraki University[1] in Fig. 1. The buildings in Hitachi campus were severely damaged, in some cases, deep into their structural frameworks. Those in Mito and Ami campuses were also strongly shaken but less damaged for they were located relatively away from the epicenters.

The main server computers were placed in Hitachi campus where the college of engineering is hosted. The server racks were so firmly fixed to the basement that they did not fall. But they were shaken so badly that we thought the hard disk drives must have been destroyed. After the main electricity got back in several days, we were relieved and even surprised to know that the disks were not damaged at all. Probably the arms in the drives were already retracted in response to the preceding smaller vibrations while the huge main shakes were traveling from the distant epicenters. Even a smaller earthquake can destroy data on the disk drives if it takes place just beneath the server room. Local fire hazards or floods can cause the same result. Data loss can give much more serious damages to the business of universities than the physical damages to the buildings.

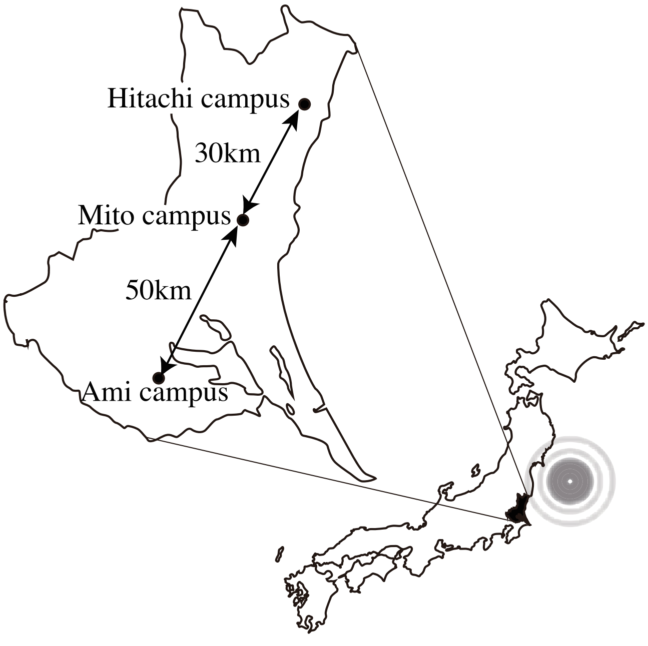

Figure 1 Three major campuses of Ibaraki University

This map shows the geographic outline of the islands and does not indicate the territory of any specific country.

It is the difficult time in disasters when we really need the means of public relation and personal communications. But the information systems of the university were completely out of operation for days due to the power failure. The main electricity were not available for three days in Hitachi and two days in Mito and Ami.

We really needed to announce what to do with the entrance examination scheduled on the next day of the earthquake. It was obvious that we could not do it as scheduled. But we had to announce how many days it would be put off or if it should be cancelled. We set up an emergency web site (Matsumoto, 2011) on a cloud service[2] to post announcements to the students and the employees. The temporary IP address was registered to the DNS server so that the accesses to the old regular site be directed to the emergency site. This emergency site helped people get informed of the announcements from the university for a few days until the regular web site came back to operation. Then we suffered from another problem that the wrongly cached DNS records in different internet service providers kept pointing the emergency site. The heroic emergency site became a ghost web site that confused people by showing outdated information persistently.

On the basis of those bitter experiences, we have redesigned and implemented the information system of our university. This system has two levels of security: (1) The web site for public relations and the e-mail systems for communications that will work continuously even in the case of power failure. (2) The personal computer systems that will be down during power failure but will restart working without any loss of data as soon as the power supply is back.

The rest of this paper is organized as follows: In Sections 2 and 3, we review the information systems and networks of this particular university, and the lessons learnt from the mega disaster caused by the 2011 earthquake, respectively. In Sections 4 and 5, we describe two kinds of solutions for the business continuity plan of the university: Uninterrupted web and mail servers; and distributed file backup system, respectively. In Section 6,

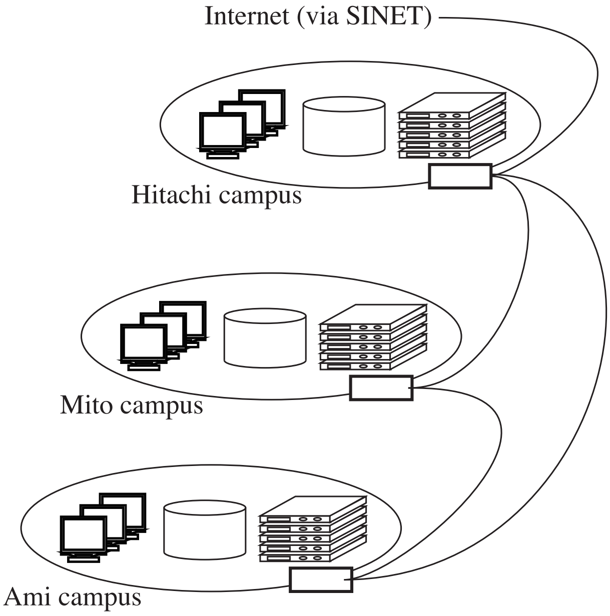

Figure 2 Network connections among the campuses.

we evaluate the file backup system through its operation in practice. Section 7 mentions several related works and Section 8 gives a concluding remark.

2 Information systems and networks of Ibaraki University before the disaster

This university has three major remote campuses as shown in Fig. 1. The center for information technology is located in Hitachi campus where the computers have been historically used much more actively than the other two campuses. That is the reason why the connection to the Internet is going through the firewall system in Hitachi as shown in Fig. 2. The campuses are connected in the star-shaped topology via the wide-area ethernet at the speed of 1Gbps with the interfaces of L3 switches.

Each campus has a file server that stores the home directory of all the users in the campus. The home directory is mounted on the PC when the user logs on and also stores mails to be referred to by the mail server for the students there. The file server also stores the systems and the data for the virtual servers on the real server computers managed by VMware.

The campuses have been often struck by power failure for a short time due to local thunder storms. Each campus has one of the IdP server systems so that the campus can be indifferent to power failure of other campuses. From time to time, we had power failure at Hitachi campus where the mail server for the staff and the main web servers are hosted. But the black out did not last more than half an hour.

That was strong enough against small disasters. But the story was different in the case of mega disaster.

3 Lessons from mega disaster and new policy

The 2011 earthquake severely damaged Hitachi campus but fortunately claimed no casualties. We lost water supply for more than 10 days, which greatly affected our life. However, in the aspect of communications, the most difficult situation was caused by the power failure for three days. The main web server and the mail server for the staff were completely down when we really needed to post announcements and discuss recovery plans to cope with the severe disaster.

The emergency web site (Matsumoto, 2011) set up on a cloud service^2 was barely fulfilling the public relations. But it took some time for this new web site to start operating while people needed information as soon as possible to know what was going on. Besides, after the regular web site came back into operation, the emergency site had suddenly become a ghost web site that confused people by showing outdated information persistently due to the wrongly cached DNS records in different internet service providers. It is a “public secret” that most of the commercial internet service providers do not observe the standard of the TTL (time-to-live) parameter of any DNS records. It is true that some cached DNS records were different from a base station to another of the same cellular carrier in the same region at the time of the last disaster.

It is the only and best policy to keep the regular web server working throughout the disaster. The same is true of the mail servers. We have never heard of temporary mail services that can substitute existing mail services of the regular use. They are useless because we do not have a means to identify the new mail addresses of students and colleagues.

The other information systems such as PCs and file servers in the universities do not have to keep operating throughout the disaster since the school can be closed after sending students safely toward home. Operations of the PCs and file servers can be resumed when people come back to the school as long as we have the data preserved.

Loss of data is better than loss of lives, but it is worse than damaged buildings and destroyed computers. It can take an enormous amount of time or may be even impossible to reproduce the lost data.

We learnt that an information system really strong against mega disasters needs to have the following two features:

(1) The web site for public relations and the e-mail systems for personal communications that will work continuously without interruption even in the case of power failure.

(2) The personal computer systems that will be down during power failure but will restart working without any loss of data as soon as the power supply is back.

The former can be implemented simply by employing the recent private or public cloud systems.

The latter requires an idea. If we employ the cloud service to keep the data safe in preparation for possible mega disasters, the data exchange between the local PC and the remote cloud causes longer latency and heavier traffic than necessary in the normal time. The users should suffer from slow response of the PC due to the latency in data retrieval from the remote storage. Frequent data exchanges between the PC and the remote storage should require wide bandwidth that will eventually increase the communications cost or slow down the data transfers.

In order to store the data in a safe place while keeping the data readily accessible at the on-premise file server, we can exploit the three remotely distributed campuses connected by the 1Gbps wide-area ethernet in the particular case of Ibaraki University. The local file server stores the data for the local users in each campus as it has been practiced normally. Let its duplicate copy be stored in a fellow file server in another campus. Then, at least one copy of the data will survive strong earthquakes just beneath the file server even if it would not give time to retract the disk arms. That will survive also local fire and flood.

4 Uninterrupted Web server and Mail server

The web and mail services can be interrupted for a short time in the normal time for people usually accept regular server maintenance. On the contrary, those services should not be interrupted in the very time of disaster since the latest information is crucial for the people to make decisions in emergency. Probably for the same reason, the cellular carriers have some key base stations supported by local electricity generators to be robust against commercial power failures.

The web site can work continuously without interruption only if the server stays physically healthy and the power is uninterrupted even in the case of commercial power failure. There are roughly two kinds of solutions by means of private and public cloud systems operated at some data centers.

The main web server of Ibaraki university has been moved into a private cloud system set up in a containerized data center built in one of the campuses. It is designed to survive the strongest earthquakes in the history of Japan and supplied with main electricity by the dedicated generator. The DNS servers are extended to include the secondary DNS service hosted in a public cloud service. We are planning to move the web server further to a public cloud service.

The mail system has emigrated to the cloud service Microsoft Office 365[3]. The IdP servers are extended to include a slave server also in a public cloud service. That is the simplest and affordable solution by virtue of the academic discount offered by Microsoft.

5 Distributed file backup system

Each campus has a file server Model VNX5300 from EMC (EMC, 2011) that stores the data to be preserved. They include the work space of students, electronic contents for the classes, and documents for class management. They are crucial for continuation of teaching activities through small or middle scale disasters or their quick recovery after mega disasters.

If we send the frequently updated large data to a remote backup server outside the university in anticipation of possible mega disasters, the data transfer from the local server to the remote server causes heavy traffic in the network in the normal time. However, the fear of losing important data has been driving several Japanese universities to start a coalition to keep the data of one another (Kumagai et al., 2012) despite the extra cost for communications and storage.

In the case of Ibaraki university where we have been suffering from the overhead cost for managing remote campuses, we have a good set of three campuses

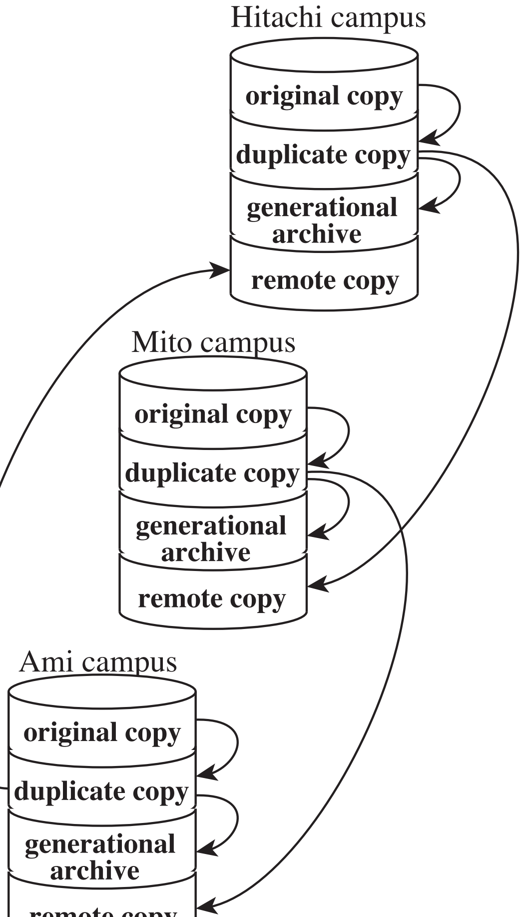

Figure 3 Structure of the copies.

geographically apart from one another. We have only to synchronize the original copy of the data with its duplicate copy in another campus. We can keep them in the plain format without any encryption that is mandatory for the coalition of several different universities.

The backup data is a simple duplicate copy of the original one. A system image of the virtual machine and its data partition in the backup can migrate onto a different real server to start working even in the case of physical damage on the original server.

Figure 3 shows a schematic diagram of the three file servers. Each disk system is partitioned into the four regions: original copy, local duplicate copy, remote duplicate copy, and local generational archive.

The local duplicate copy is just for increasing the robustness against malfunction of the disk systems. The file server VNX5300 offers the capability of updating the local duplicate copy immediately when the original copy is modified.

The remote duplicate copy in another campus is also updated by the same mechanism except that the updates take place not immediately but every 10 minutes. This time interval of 10 minutes is a parameter that can be tuned in accordance with the real situation. A too short interval may increase the base load traffic. A too long interval may cause a burst traffic to transfer piled up updates at a time.

The local generational archive stores an ordinary incremental backup data from which users can reverse their file operations.

No data are encrypted since everything is under the control of the same institute. Nor are they even compressed. Backup data in the same plain format as the original are advantageous to save computational load for encryption and compression, and troubles for decryption and extraction in case the backup copy is needed in emergency.

6 Experiments

The traffic observed at the inter-campus L3 switches before and after the deployment of new backup system in March 2012 is plotted in Fig. 4. It includes that for ordinary activities of accessing data, such as web pages across the campuses, other than the synchronization of data storage. Here we see how much the new system increased the whole traffic. The traffic was measured during the two semesters in the school year of 2011 and those in that of 2012. In the period of the measurement, the time interval of synchronization was set to the constant value of 10 minutes.

The measured traffic was averaged for the same day of the week in the semester periods. Variations from day to day of the week depend mainly on the change in the timetable of the classes.

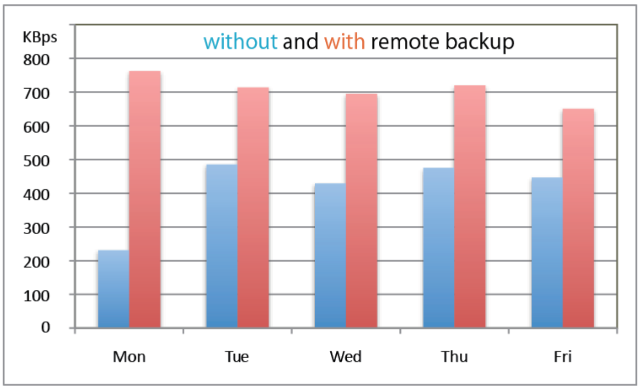

Figure 4 Averaged peak traffic of the day without (2011) and with (2012) the remote backup system.

The traffic has increased by roughly 1.5 times in total. But it stays less than 1M Bytes per second. For the wide-area ethernet connecting the campuses at the maximum speed of 1G bits per second, the new traffic rate is a moderate good figure not too low nor high.

The time interval of synchronization is a parameter that can be varied in accordance with the situation. In the fall semester of 2015, traffic trends in the typical busy days of the week, Tuesday and Thursday, were measured for various synchronisation intervals during the day time. Figures 5 to 9 show traffic trends during the day time in one day of either Tuesday or Thursday when the synchronisation interval was set as 2, 5, 10, 20 or 40 minutes. hose intervals were chosen to form a roughly doubling sequence starting at 2 minutes. We did not dare to attempt the 1 minute interval that we thought too frequent.

The case of 10 minutes in Fig. 7 can be regarded as an exceptionally busy day when the students happened to be extraordinarily active in computer usage because the peak, average and even lowest traffic rates are exceptionally high. In this case, the traffic is persistently high around the average 21.4MBps throughout the day time and makes two peaks reaching higher than 30MBps. It drops only once at 16:30 in the evening with a notch down only to 12MBps when we had a ten-minute break between the classes.

In the other cases, the traffic goes sharply up and down making peaks as high as 30MBps and deep notches as low as 5MBps probably in response to the teachers' instructions for file operations in the classrooms. The high traffic tends to appear at the end of classes and the low traffic does during the breaks between classes.

Except for the case of Fig. 7, the lowest traffic appears as notches in Figs. 5, 6, 8 and 9 at roughly the same level of 5MBps. The frequent synchronization by the interval of 2 minutes caused the highest average traffic rate of 21.3MBps in Fig. 5. The average traffic rate follows the tendency of going down to 20.9MBps for the 5 minutes interval in Fig. 6 and to 18.5MBps for the 20 minutes interval in Fig. 8 as the synchronization interval gets longer.

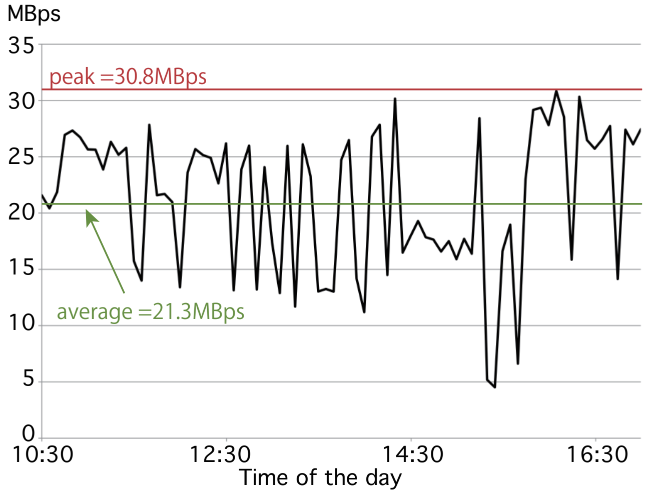

Figure 5 Traffic trend for the synchronization interval of 2 minutes.

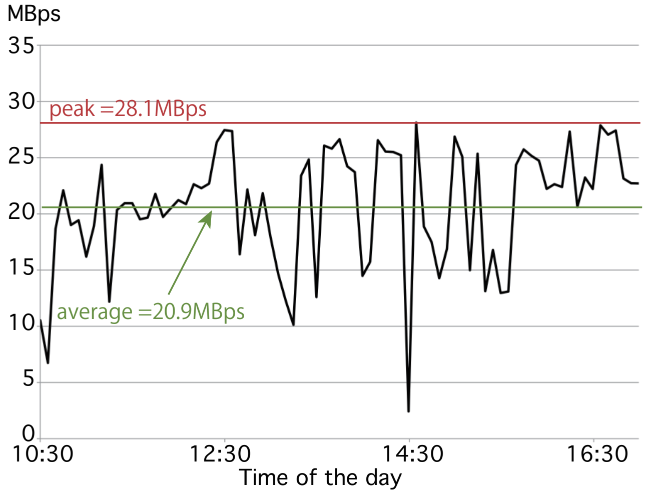

Figure 6 Traffic trend for the synchronization interval of 5 minutes.

On the contrary, the highest peak of 31.8MBps was observed for the synchronization interval of 40 minutes in Fig. 9 and the second highest peak of 31.7MBps was for 20 minutes in Fig. 8. Those high peaks must have been caused by burst traffic of large updated data of which synchronization was suspended for a longer time.

On the basis of those example data, we may say the optimal choice of the synchronization interval is around 5 minutes in this fall semester. But, of course, the optimal choice depends on the user activities in the day or even in the hour. We need some intelligent methods in order to estimate the optimal value of the synchronization interval adaptively. At the same time, we can also say that the choice of the synchronization interval does not so wildly push the peak and average up to an intolerable level.

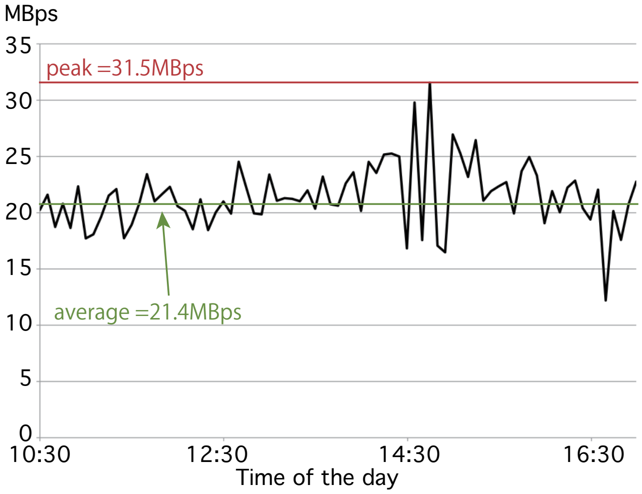

Figure 7 Traffic trend for the synchronization interval of 10 minutes.

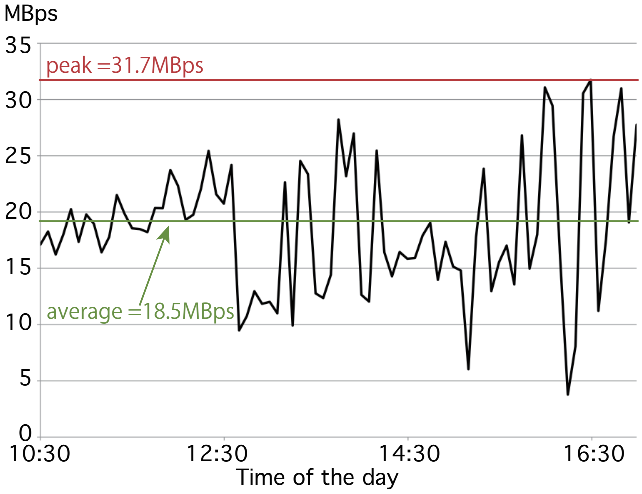

Figure 8 Traffic trend for the synchronization interval of 20 minutes.

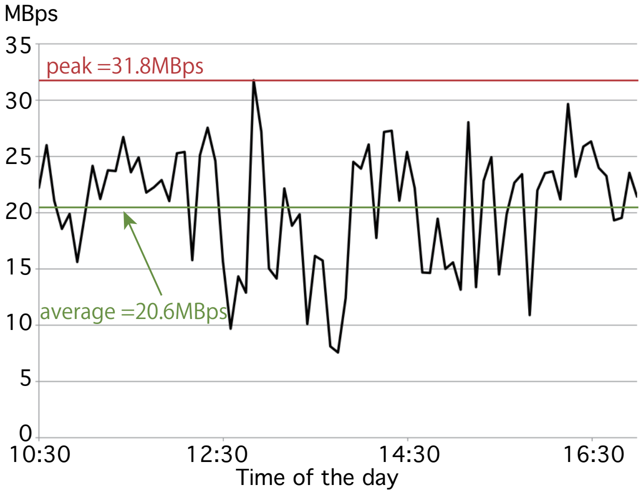

Figure 9 Traffic trend for the synchronization interval of 40 minutes.

7 Related works

There have been different solutions for file backup systems designed against mega disasters.

The simplest solution is schematized in Fig. 10 and employs a commercial cloud storage (Iwano et al., 2013) hosted at a remote place. The duplicate copy on a remote cloud storage can be synchronized to the data on the local storage from time to time through a secure channel like SSL. We do not have to encrypt the backup data in the case that the contract secures their privacy. If the privacy level does not meet the standard of the university, we have to encrypt the files before sending them to the remote side and we can downgrade the channel security. Frequent synchronization increases the computational and communications cost. It is recommended for the universities to send data at night when the computational and communications resources are more available.

In order to lower the communications cost, a pair of universities have been practicing the mutual backup storage service in Fig. 11. We have to encrypt the files before sending them to the other side. The two universities should trust each other in regard of the maintenance of the storage devices. In order not to bother the network traffic of each other, it is recommended for the universities to send data only at night.

There is an advanced scheme (Kumagai et al., 2012) for mutual data backup among not so trusting universities by means of (n, t)-threshold secret sharing scheme that can be applied to a coalition of n universities as shown in Fig. 12. A university, owner of a file, makes n shares of the file and sends them to the other $n-1$ universities. The file can be recovered from its t shares even if $n-t$ shares are lost accidentally or due to mega disasters. The file is kept secret unless t universities betray the owner at the same time. There is even a more advanced version for the use on cloud storage service (Ohigashi et al. , 2014). These are the most widely applicable schemes at the cost of calculating the shares and communicating more data for the sake of redundancy.

In the particular case of Ibaraki university, we happened to have remotely distributed campuses in the same organization as depicted in Fig. 13. The system simply keeps a duplicate copy of the file at another campus. By virtue of this simplicity, the synchronization of data can be made as frequently as almost in real time. The experience reported in this paper will be of reference to other universities having two or more campuses moderately apart from each other.

8 Conclusions

Through the bitter experiences during the disaster in March 2011, we have redesigned the information system

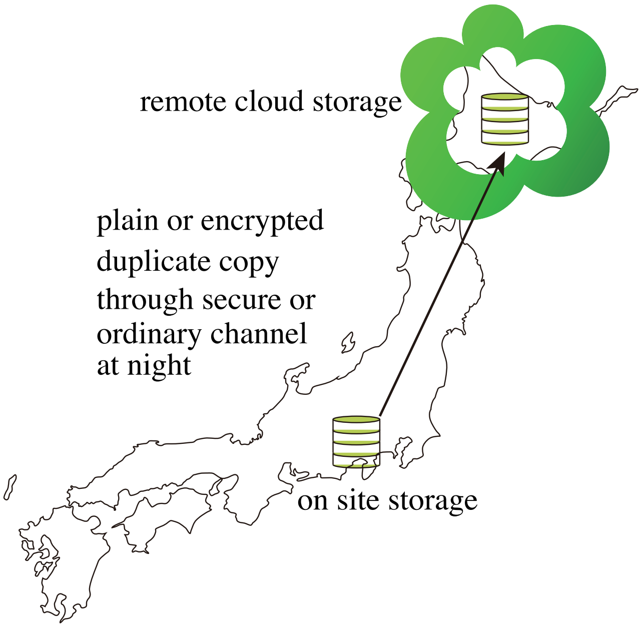

Figure 10 Employment of a commercial remote cloud storage.

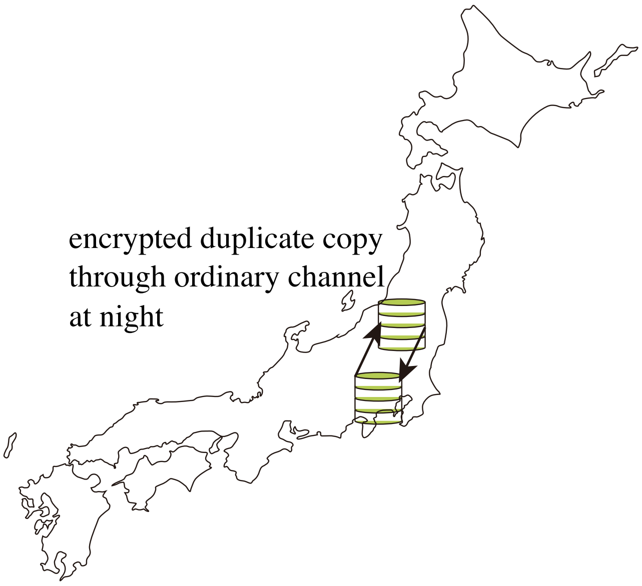

Figure 11 Mutual back up storage between two universities trusting each other.

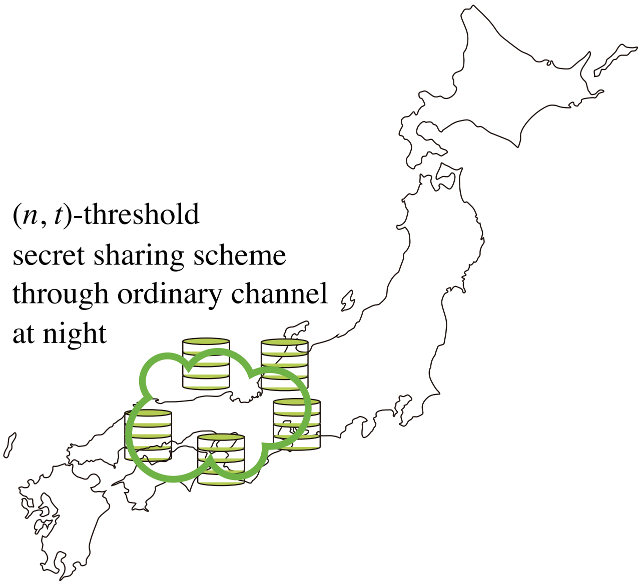

Figure 12 Mutual back up storage among not so trusted universities.

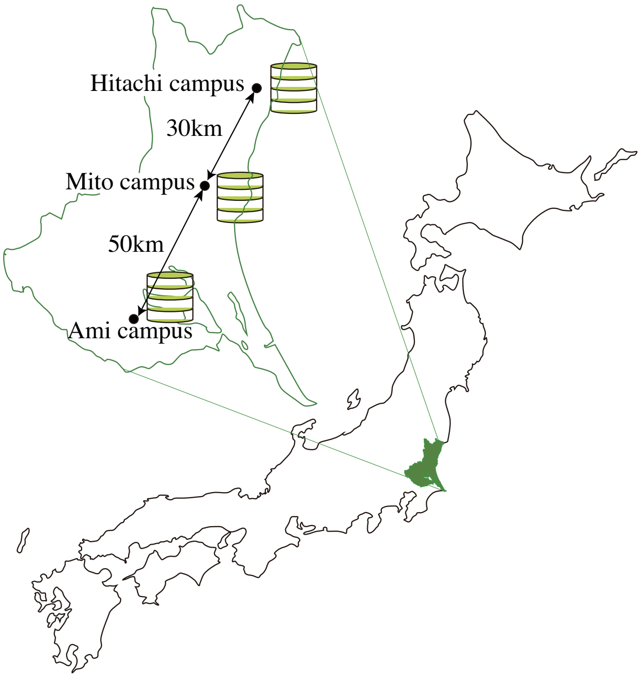

Figure 13 Near real-time back up storage among remote campuses of the same university.

for Ibaraki university. The web site and e-mail systems were moved to the private and public cloud services so that they will never be interrupted again. The file servers are made secure by keeping a duplicate copy in another campus which is located more than 30 km away.

Taking advantage of the remote campuses, we designed and implemented a file storage system that keeps the original copy on-premise in a campus and its backup copy in one of the other two campuses. Its operations have shown that the communication traffic among the campuses increased only by half in order to keep the data safe against natural disasters.

Additional experiments for various values of the synchronization interval have indicated the tendency that the shorter intervals cause the higher average traffic and a very long interval causes a high peak traffic to exchange data updates suspended for the long interval. At the same time, it has also been confirmed that the choice of the synchronization interval does not so wildly push the peak and average up to an intolerable level for current practice with this particular university.

There must be the optimal choice of the synchronization interval that depends on the user activities in the day or even in the hour. We need some intelligent methods in order to estimate the optimal value of the synchronization interval adaptively, which is left for further research in the future.

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Note

[1] http://www.ibaraki.ac.jp/
[2] http://cloudpack.jp/
[3] https://products.office.com/

3.プロジェクト業績

活動実績

【都市インフラの強靭化技術開発】

炭素繊維やバサルト繊維による構造補強材の高性能化により、インフラ構造物の耐震性やResilience（自己回復性）向上手法を開発し、都市インフラの強靭化技術に関する取り組みを行っており、産学連携を検討している。
（呉教授）

【都市インフラモニタリングや知能化による高度化センサ技術の開発】

1）光ファイバセンサ方式とカーボンファイバセンサ方式による長寿命・高性能化された分布型領域センサの実製作・性能究明および実用性を実験室レベルで検討した。
２）領域センサにより得られるひずみ分布の直接利用により、構造物の早期損傷検知に対する各種指標を検討した。
３）開発したセンサ、装置、検知アルゴリズムを基に、早期損傷検知システムを開発し、茨城県内のRC桁橋、新潟県内の既損傷PC箱桁橋、東北新幹線高架橋、中国の蘇通大橋（１０００m級長大橋）など既設構造物のリアルタイム健全性評価システムの検証を進めている。
４）高度化された光ファイバ分布センシング技術による広域地圏環境（河川堤防・地すべり）防災システムの構築に関する産官学連携プロジェクトを開始し、基礎検討を行っている。
（呉教授）

【センサデータの安定した通信/解析技術の開発と省電力化推進】

1）大規模災害により、電源インフラが完全消失した状況において、市民にどのように、情報を伝達するか、また市民の安否情報をどのように収集するかについて研究を進めている。内部電源を必要としないUHF帯RFIDを利用している。（武田教授）

【老朽化したインフラ構造物の災害リスクを考慮した維持管理計画】

1）橋梁の（異常監視）ヘルスモニタリングシステムの実証実験を常陸大宮市の引田橋での継続的に実施した。（齋藤特命教授,原田准教授, 鎌田教授）
2）ひたちなか海浜鉄道湊線での企業との傾斜計の実証実験を推進. 本件は10月に茨城県土木部との連携で常陸大宮地区の地すべり危険地域への応用予定（齋藤特命教授）
3）構造物の耐久性設計に資する高度化シミュレーション技術を開発している（車谷准教授）

【UAV を活用した新たな空間情報の防災システムへの活用と超小型衛星との連携】

1) 茨城県生活安全部と UAV による安全監視・不法投棄防止システムの実現の連携検討を開始した。（齋藤特命教授）
2) 宮城教育大学との UAV を用いた空間環境情報可視化と津波災害地域の空撮を行った。（齋藤特命教授）
3) 宮城県石巻市、女川町での空撮による災害地域の土地利用変化、震災遺構の映像保存プロジェクトをスタートさせた。（齋藤特命教授）

【アウトリーチとしての防災・減災、それらを含む環境教育の実施】

1) ひたちなか市外野小学校、前渡小学校にて環境・情報教育を実施した。（齋藤特命教授）
2) (社)次世代センサ協議会第 44 回センサ＆アクチュエータ技術シンポジウムにて UAV と防災について講演した。（齋藤特命教授）

【災害時および平常時等における情報共有法】
1) 防災情報を配信する方法には、インターネットやＦＭ放送、拡声器などを利用する方法があるが一長一短がある。そこで追加手段の１つとして交通信号機を配信局として用いる方法を研究している。特に、光点滅（ＬＥＤのオンオフ、人間の目ではそのオンオフは感知できない）による光ワイヤレス通信の高信頼化について検討している。
2) 大規模震災では、集中制御が基となる携帯網・ワイヤレス通信網では情報共有は難しいまた、信号機等の停電により大規模な車両渋滞が生じると考えられる。その渋滞車両を積極的に通信局として利用するネットワーク網を構築する研究を進めている。ＭＡＣプロトコルとして、変形２進カウントダウン法を考案している。（羽渕裕真教授）

【地元企業・学校等との学術連携実現】

1) 土木部河川課ダム砂防室との連携により，UAV によるダム堤体表面のクラックマップ生成について連携して研究した。（齋藤特命教授）

【地域社会活動】

1) 鎌田　賢：第 38 回全国高等学校総合文化祭「いばらき総文祭 2014」コンピュータ部門のプログラミングコンテストにおいて、予選・本選（平成 26 年 7 月 28 日（月）29 日（火））の審査委員を務めた。本選ではデモ展示も行った。

【他大学・企業・自治体連携での研究資金獲得】

1）東北大学と共同で申請した科研費（挑戦的萌芽）「地盤中の間隙水の挙動調査」採択（東北大学風間基樹教授，茨城大学安原一哉名誉教授，鎌田賢教授）（齋藤修特命教授の企画・アレンジによる）において、地中埋め込み型の土砂内水流・水圧センサと無線モジュールを開発した。
2）シンポジウム「SICE 計測部門セミナー 都市のスマートセンシング」を企画して開催した。（齋藤特命教授）
http://rcl.it.aoyama.ac.jp/sice-sss/sice_seminar_20140917.html

【自治体との各種連絡会議推進（茨城県・日立市・ひたちなか市等）】

1）茨城県商工労働部、土木部、企画部、生活安全部との定期情報交換（齋藤特命教授）（鎌田教授，桑原教授は随時参加）
2）ひたちなか市長との情報交換会１回／年度（齋藤特命教授）（鎌田教授，桑原教授は随時参加）

【国際共同研究を実施（中国、韓国等）】

1）センシング技術による地下鉄防災システムの高度化に関する共同研究を英国のケンブリッジ大学、長大橋の長寿命化に関する研究を中国の東南大学、光ファイバ技術による高速道路橋の長期モニタリングに関してアメリカＦＨＷＡ（連邦道路管理局）橋梁の長期性能検討プロジェクトチームなどと共同研究により推し進めている。（呉教授他）

【大学院生の教育】

1）５名の社会人博士課程入学者をリクルートした 2013 年度につづき、2014 年度には３名の社会人博士課程入学者をリクルートした。（齋藤特命教授）センター教員の連携による指導体制を構築している。2016 年度　修了１名。

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5) 山本純平，外岡秀行，ディープラーニングによる衛星画像の雲判別の可能性，日本リモートセンシング学会第61回学術講演会論文集, pp. 179-180, 2016年11月.

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【受賞等】

1) 呉教授が、建設に関する繊維複合材料国際学会（International Institute for FRP in Construction、IIFC、本部：カナダ）の IIFC メダル賞を受賞した。IIFC メダル賞は、同学会の最高位賞と位置付けられており、2006 年の設立以降、2 年に 1 人が選ばれ、日本からの受賞は呉教授が初めてとなった。

【競争的資金獲得】

1.採択された競争的資金等の外部資金

1) 電気通信普及財団 研究助成金，「消失通信路に耐性のある光無線ターボ符号システムに関する研究」 1,000,000 円，2015 年度，研究代表者: 羽渕裕真

2) 受託研究 JAXA，「地球観測用小型赤外カメラ(CIRC)に関する校正検証」、平成 27 年度，研究代表者: 外岡秀行

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4) 民間企業との共同研究，「スマートグラスの処理、チューニング方法等の助言」，研究代表者: 鎌田賢

5) 民間企業との共同研究，「路面状態センシング方式と放射分光応用に関する研究」，研究代表者: 外岡秀行

6) 民間企業との共同研究，「AI 技術を利用した水害対処の研究」，研究代表者: 桑原祐史

7) 千葉大学との共同研究，「生活環境圏における CO2 濃度の計測と検証」，研究代表者: 桑原祐史

8) 地域法人との共同研究,「訪日外国人観光客を対象とした AR スマホアプリ(iOS 版)の研究開発」, 研究代表者: 石田智行

9) 地域法人との共同研究,「訪日外国人観光客を対象とした AR スマホアプリ(Android 版)の研究開発」, 研究代表者: 石田智行

2.採択された科学研究費補助金

1）　科研費　基盤（C）　（研究課題番号 16K06528）
生活環境圏における CO2 濃度の地域性に着目した新たな緑地評価指標の提案　桑原祐史（茨城大学）　分担　久世宏明　（千葉大学）
研究期間　2016 年 4 月 1 日～2019 年 3 月 31 日
研究費総額 4,550,000 円

2）　科研費　基盤（B）　（研究課題番号 15H02693）
大規模災害時の劣悪通信環境で繋がる次世代ネバー・ダイ・ネットワークとその応用
代表　柴田義孝（岩手県立大学）　分担　石田智行（茨城大学）
研究期間　2015 年 4 月 1 日～2018 年 3 月 31 日
研究費総額 7,150,000 円

3）　科研費　挑戦的萌芽研究　（研究課題番号：26630215）
課題名　地盤中の水の挙動の調査を格段に進展できるワイヤレスマルチセンサの開発への挑戦
代表　風間基樹（東北大学）　分担　安原一哉，鎌田賢（茨城大学）
研究期間　2014 年 4 月 1 日～2017 年 3 月 31 日
研究費総額 4,915,000 円

4）　科研費　基盤研究（C）　（研究課題番号：26420409）
課題名　可変張力つき 2 変数スプラインの導出とその画像補間への応用
代表　鎌田賢（茨城大学）
研究期間　2014 年 4 月 1 日～2017 年 3 月 31 日
研究費総額　1,700,000 円

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「知的で持続可能な社会基盤および防災セキュリティ技術研究創出事業」

茨城大学工学部附属防災セキュリティ技術教育研究センター

２０１６年度報告書

発行日　　平成 29 年 4 月

発行者　　茨城大学　工学部　都市システム工学科
教授　呉　智深
〒316-8511 日立市中成沢町 4-12-1
Tel: 0294-38-5179　Fax: 0294-38-5268

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