Asunto: Solicitud EP
Fecha de envío: 15/10/2010
Número de páginas: 38 (incluida ésta)

Para: Servicio de Patente Europea y PCT
A la atención de: Luis Miguel Simón
Número de teléfono: 91 349 85 43
Número de fax: 91 349 53 04

De: Eva Villalón Martín
Número de teléfono: 93 413 40 70
Número de fax: 93 413 76 31

Comentarios: Título de la solicitud EP:

"A METHOD OF MEASURING A DISPLACEMENT-RELATED PARAMETER USING A LASER SELF-MIXING MEASURING SYSTEM, AND A LASER SELF-MIXING MEASURING SYSTEM"

Se envía por fax para el registro EP la solicitud mencionada arriba.

Les enviaremos por correo ordinario tres copias de dicha solicitud EP.

Reciban un cordial saludo,

Eva Villalón Martín
Oficina de Patentes y Licencias
Universitat Politècnica de Catalunya

Europäisches Patentamt
European Patent Office
Office européen des brevets

Antrag auf Erteilung eines europäischen Patents
Request for grant of a European patent
Requête en délivrance d'un brevet européen

☐ Nachreichung von Form 1001 zu einer früher eingereichten Anmeldung nach Regel 40 (1) vom
Form 1001 filed further to a previous application under Rule 40(1) on
Dépôt du formulaire 1001 pour une demande déposée antérieurement au titre de la règle 40(1) en date du

☐ Bestätigung einer bereits durch Fax eingereichten Anmeldung vom / Confirmation of an application already filed by fax on / Confirmation d'une demande déjà déposée par téléfax le — bei / with / auprès de

Nur für amtlichen Gebrauch / For official use only / Cadre réservé à l'administration

1	Anmeldenummer / Application No. / N° de la demande	MKEY	
2	Tag des Eingangs (Regel 35 (2)) / Date of receipt (Rule 35(2)) / Date de réception (règle 35(2))	DREC	
3	Tag des Eingangs beim EPA (Regel 35 (4)) / Date of receipt at EPO (Rule 35(4)) / Date de réception à l'OEB (règle 35(4))	RENA	
4	Anmeldetag / Date of filing / Date de dépôt		

5 Es wird die Erteilung eines europäischen Patents und gemäß Artikel 94 die Prüfung der Anmeldung beantragt. / Grant of a European patent, and examination of the application under Article 94, are hereby requested. / Il est demandé la délivrance d'un brevet européen et, conformément à l'article 94, l'examen de la demande. ☒ EXAM 4

Prüfungsantrag in einer zugelassenen Nichtamtssprache / Request for examination in an admissible non-EPO language / Requête en examen dans une langue non officielle autorisée

5.1 Der Anmelder verzichtet auf die Aufforderung nach Regel 70 (2), zu erklären, ob die Anmeldung aufrechterhalten wird. / The applicant waives his right to be asked whether he wishes to proceed further with the application (Rule 70(2)). / Le demandeur renonce à être invité, conformément à la règle 70(2), à déclarer s'il souhaite maintenir sa demande. ☐ MEPA

6 Zeichen des Anmelders oder Vertreters (max. 15 Positionen) / Applicant's or representative's reference (max. 15 keystrokes) / Référence du demandeur ou du mandataire (max. 15 caractères ou espaces) — AREF: EP15/10/2010

Anmelder / Applicant / Demandeur — APPR

7 Name / Nom
8 Anschrift / Address / Adresse

UNIVERSITAT POLITÈCNICA DE CATALUNYA

C/Jordi Girona, 31
08034 Barcelona
España

9 Zustellanschrift / Address for correspondence / Adresse pour la correspondance

Oficina de Patents i Llicències - UPC
C/Jordi Girona, 29
Edificio Nexus II, planta baja
08034 Barcelona
España

TRAN | FILL

Zeichen des Anmelders / Applicant's reference / Référence du demandeur: EP15/10/2010

EPA/EPO/OEB 1001.1 10.10

10	Staat des Wohnsitzes oder Sitzes / State of residence or of principal place of business / Etat du domicile ou du siège	ES
11	Staatsangehörigkeit / Nationality / Nationalité	ES
12	Telefon / Telephone / Téléphone	
13	Fax / Téléfax	
14	Weitere(r) Anmelder auf Zusatzblatt / Additional applicant(s) on additional sheet / Autre(s) demandeur(s) sur feuille supplémentaire	☐

Vertreter / Representative / Mandataire FREP

15	Name / Nom (**Nur einen** Vertreter oder den Namen des Zusammenschlusses angeben, der in das Europäische Patentregister einzutragen ist und an den zugestellt wird) / (Name **only one** representative or association of representatives, to be listed in the Register of European Patents and to whom communications are to be notified) / (N'indiquer **qu'un seul** mandataire ou le nom du groupement de mandataires qui sera inscrit au Registre européen des brevets et auquelles les significations seront faites)	
		et al
16	Geschäftsanschrift / Address of place of business / Adresse professionnelle	
17	Telefon / Telephone / Téléphone	
18	Fax / Téléfax	
19	Weitere(r) Vertreter auf Zusatzblatt / Additional representative(s) on additional sheet / Autre(s) mandataire(s) sur feuille supplémentaire	☐

Vollmacht / Authorisation / Pouvoir GENA

20	ist beigefügt / is enclosed / joint	☐
21	Allgemeine Vollmacht ist registriert unter Nummer / General authorisation has been registered under No. / Un pouvoir général a été enregistré sous le numéro	

Erfinder / Inventor / Inventeur INVT 20

22	Der (die) Anmelder ist (sind) alleinige(r) Erfinder. / The applicant(s) is (are) the sole inventor(s). / Le(s) demandeur(s) est (sont) le(s) seul(s) inventeur(s).	☐
23	Erfindernennung in beigefügtem Schriftstück / Designation of inventor attached / Voir la désignation de l'inventeur ci-jointe	☐

24 **Bezeichnung der Erfindung / Title of invention / Titre de l'invention** TIDE TIEN TIFR

A METHOD OF MEASURING A DISPLACEMENT-RELATED PARAMETER USING A LASER SELF-MIXING MEASURING SYSTEM, AND A LASER SELF-MIXING MEASURING SYSTEM

Zeichen des Anmelders / Applicant's reference / Référence du demandeur: EP15/10/2010

EPA/EPO/OEB 1001.2 10.10

25 Prioritätserklärung (Regel 52) / Declaration of priority (Rule 52) / Déclaration de priorité (règle 52)

PRIO

Eine Prioritätserklärung wird für die folgenden Anmeldungen abgegeben: /
A declaration of priority is hereby made for the following applications: /
Une déclaration de priorité est produite pour les demandes suivantes :

Nur für amtlichen Gebrauch / For official use only / Cadre réservé à l'administration

01			
02			
03			
04			

	Staat / State / Etat	Anmeldetag / Date of filing / Date de dépôt	Aktenzeichen / File No. / N° de dépôt
01			
02			
03			
04			

25.1 Weitere Prioritätserklärung(en) auf Zusatzblatt / Additional declaration(s) of priority on additional sheet / Autre(s) déclaration(s) de priorité sur feuille supplémentaire ☐

25.2 Diese Anmeldung ist eine vollständige Übersetzung der früheren Anmeldung. / This application is a complete translation of the previous application. / La présente demande est une traduction intégrale de la demande antérieure.

☐ 01 ☐ 02 ☐ 03 ☐ 04 ☐ andere / other / autres

25.3 Es ist nicht beabsichtigt, eine (weitere) Prioritätserklärung einzureichen. / It is not intended to file a (further) declaration of priority. / Il n'est pas envisagé de produire une (autre) déclaration de priorité. ☐

26 Bezugnahme auf eine früher eingereichte Anmeldung / Reference to a previously filed application / Renvoi à une demande déposée antérieurement

EAPP

26.1 Es wird auf eine früher eingereichte Anmeldung Bezug genommen. Die Bezugnahme ersetzt die Beschreibung und etwaige Zeichnungen (Regel 40 (1) c), (2)). Die Anmeldung, auf die Bezug genommen wird, ist: / Reference is made to a previously filed application. That reference replaces the description and any drawings (Rule 40(1)(c), (2)). The application to which reference is made is the following: / Il est fait référence à une demande déposée antérieurement. Ce renvoi remplace la description et, le cas échéant, les dessins (règle 40(1)c), (2)). La demande à laquelle il est fait référence est la suivante : ☐

Nur für amtlichen Gebrauch / For official use only / Cadre réservé à l'administration

Staat / State / Etat	Anmeldetag / Date of filing / Date de dépôt	Aktenzeichen / File No. / N° de dépôt

26.2 Die Bezugnahme auf die früher eingereichte Anmeldung ersetzt auch die Patentansprüche (Regel 57 c)). / The reference to the previously filed application also replaces the claims (Rule 57(c)). / Le renvoi à la demande déposée antérieurement remplace également les revendications (règle 57c)). ☐

26.3 Eine beglaubigte Abschrift der früher eingereichten Anmeldung (Regel 40 (3)) / A certified copy of the previously filed application (Rule 40(3)) / Une copie certifiée conforme de la demande déposée antérieurement (règle 40(3))

☐ ist beigefügt. / is attached. / est jointe. ☐ wird nachgereicht. / will be supplied later. / sera produite ultérieurement.

26.4 Eine Übersetzung der früher eingereichten Anmeldung (Regel 40 (3)) / A translation of the previously filed application (Rule 40(3)) / Une traduction de la demande déposée antérieurement (règle 40(3))

☐ ist beigefügt. / is attached. / est jointe. ☐ wird nachgereicht. / will be supplied later. / sera produite ultérieurement.

27 Teilanmeldung / Divisional application / Demande divisionnaire

PANR

Die Anmeldung ist eine Teilanmeldung, die aus der folgenden früheren Anmeldung hervorgeht: / The application is a divisional application based on the following earlier application: / La présente demande constitue une demande divisionnaire relative à la demande antérieure suivante :

DFIL

Nummer der früheren Anmeldung / Number of earlier application / Numéro de la demande antérieure

EPA/EPO/OEB 1001.3 10.10

Zeichen des Anmelders / Applicant's reference / Référence du demandeur: EP15/10/2010

27.1 Datum des ersten Bescheids der Prüfungsabteilung zu der frühesten Anmeldung, zu der ein Bescheid ergangen ist (Regel 36 (1) a)): / Date of Examining Division's first communication in respect of the earliest application for which a communication has been issued (Rule 36(1)(a)): / Date de la première notification de la division d'examen relative à la demande la plus ancienne pour laquelle une notification a été émise (règle 36(1)a)) :

Datum / Date

Bei Abweichung von der in Feld 27 angegebenen Anmeldung ist die betreffende früheste Anmeldung: / If different from the application mentioned in Section 27, the relevant earliest application is: / Si la demande la plus ancienne concernée diffère de celle mentionnée à la rubrique 27, veuillez indiquer son numéro :

Nummer der betreffenden frühesten Anmeldung / Number of the relevant earliest application / Numéro de la demande la plus ancienne concernée

27.2 Datum des Bescheids, in dem die Prüfungsabteilung zum ersten Mal eingewandt hat, dass die frühere Anmeldung nicht den Erfordernissen des Artikels 82 genügt (Regel 36 (1) b)): / Date of communication in which the Examining Division has objected for the first time that the earlier application does not meet the requirements of Article 82 (Rule 36(1)(b)): / Date de la notification dans laquelle la division d'examen a objecté pour la première fois que la demande antérieure ne satisfait pas aux exigences de l'article 82 (règle 36(1)b)) :

Datum / Date

28 Anmeldung nach Artikel 61 (1) b) / Article 61(1)(b) application / Demande selon l'article 61(1)b)

☐ EANR

Es handelt sich um eine Anmeldung nach Artikel 61 (1) b). / The application is an Article 61(1)(b) application. / La présente demande constitue une demande selon l'article 61(1)b).

Nummer der früheren Anmeldung / Number of earlier application / Numéro de la demande initiale

29 Patentansprüche / Claims / Revendications

CLMS

Zahl der Patentansprüche / Number of claims / Nombre de revendications: 15

29.1 ☐ wie beigefügt / as attached / telles que jointes en annexe

29.2 ☐ wie in der früher eingereichten Anmeldung (siehe Feld 26.2) / as in the previously filed application (see Section 26.2) / telles que figurant dans la demande déposée antérieurement (voir rubrique 26.2)

29.3 ☐ Die Patentansprüche werden nachgereicht. / The claims will be filed later. / Les revendications seront produites ultérieurement.

30 Abbildungen / Figures / Figures

DRAW 2

Zur Veröffentlichung mit der Zusammenfassung wird vorgeschlagen Abbildung Nr. / It is proposed that the abstract be published together with figure No. / Il est proposé de publier avec l'abrégé la figure n°: 1

31 Benennung von Vertragsstaaten / Designation of contracting states / Désignation d'Etats contractants

DEST

Alle Vertragsstaaten die dem EPÜ bei Einreichung der europäischen Patentanmeldung angehören, gelten als benannt (Artikel 79 (1)). / All the contracting states party to the EPC at the time of filing of the European patent application are deemed to be designated (Article 79(1)). / Tous les Etats contractants qui sont parties à la CBE lors du dépôt de la demande de brevet européen sont réputés désignés (Article 79(1)).

32 Verschiedene Anmelder für verschiedene Vertragsstaaten / Different applicants for different contracting states / Différents demandeurs pour différents Etats contractants

APPR02

Name(n) des (der) Anmelder(s) und benannte Vertragsstaaten: /
Name(s) of applicant(s) and designated contracting states: /
Nom(s) du (des) demandeur(s) et des Etats contractants désignés :

33 Erstreckung des europäischen Patents / Extension of the European patent / Extension des effets du brevet européen

EXPT

Diese Anmeldung gilt als Antrag, die europäische Patentanmeldung und das darauf erteilte europäische Patent auf alle Nichtvertragsstaaten des EPÜ zu erstrecken, mit denen am Tag der Einreichung der Anmeldung Erstreckungsabkommen in Kraft sind. Der Antrag gilt jedoch als **zurückgenommen**, wenn die Erstreckungsgebühr nicht fristgerecht entrichtet wird. /
This application is deemed to be a request to extend the European patent application and the European patent granted in respect of it to all non-contracting states to the EPC with which extension agreements are in force on the date on which the application is filed. However, the request is **deemed withdrawn** if the extension fee is not paid within the prescribed time limit. /
La présente demande est réputée constituer une requête en extension des effets de la demande de brevet européen et du brevet européen délivré sur la base de cette demande à tous les Etats non parties à la CBE avec lesquels des accords d'extension sont en vigueur à la date du dépôt de la demande. Cette requête est toutefois **réputée retirée** si la taxe d'extension n'est pas acquittée en temps utile.

33.1 Es ist derzeit beabsichtigt, die Erstreckungsgebühr(en) für die nebenstehend angekreuzten Staaten zu entrichten. /
It is currently intended to pay the extension fee(s) for the states marked opposite with a cross. /
Il est actuellement envisagé de payer la (les) taxe(s) d'extension pour les Etats dont le nom est coché ci-contre.

Hinweis: Im automatischen Abbuchungsverfahren werden nur für die hier angekreuzten Staaten Erstreckungsgebühren abgebucht, sofern dem EPA nicht vor Ablauf der Zahlungsfrist ein anderslautender Auftrag zugeht.

Note: Under the automatic debiting procedure, extension fees will only be debited for states indicated here, unless the EPO is instructed otherwise before expiry of the period for payment.

Veuillez noter que dans le cadre de la procédure de prélèvement automatique des taxes d'extension, le compte est débité du montant dû seulement pour les Etats cochés ici, sauf instruction contraire reçue avant l'expiration du délai de paiement.

☐ **BA** Bosnien und Herzegowina / Bosnia and Herzegovina / Bosnie-Herzégovine

☐ **ME** Montenegro / Montenegro / Monténégro

☐

☐

(Platz für Staaten, mit denen nach Drucklegung dieses Formblatts Erstreckungsabkommen in Kraft treten oder für die am Anmeldetag der früheren Anmeldung Erstreckungsabkommen in Kraft waren (Artikel 76 (1)) / Space for states with which extension agreements enter into force after this form has been printed or for which extension agreements existed on the date of filing of the earlier application (Article 76(1)) / Espace prévu pour des Etats à l'égard desquels des accords d'extension entreront en vigueur après l'impression du présent formulaire ou étaient en vigueur à la date de dépôt de la demande antérieure (article 76(1)))

34 Biologisches Material / Biological material / Matière biologique

☐ BIOM 1

34.1 Die Erfindung verwendet und/oder bezieht sich auf biologisches Material, das nach Regel 31 hinterlegt worden ist. /
The invention uses and/or relates to biological material deposited under Rule 31. /
L'invention utilise et/ou concerne de la matière biologique déposée conformément à la règle 31.

a Die nach Regel 31 (1) c) erforderlichen Angaben, d. h. die Hinterlegungsstelle und die Eingangsnummer, sind in den technischen Anmeldungsunterlagen enthalten auf /
The information required under Rule 31(1)(c), i.e. depositary institution and accession number, is given in the application's technical documents on /
Les indications visées à la règle 31(1)c), à savoir l'autorité de dépôt et le numéro d'ordre, figurent dans les pièces techniques de la demande à la / aux

Seite(n) / page(s)	*Zeile(n) / line(s) / ligne(s)*

b Ist die Eingangsnummer am Anmeldetag noch nicht bekannt, so sind die Hinterlegungsstelle und das (die) Bezugszeichen (Nummer, Symbole usw.) des Hinterlegers in den technischen Anmeldungsunterlagen zu entnehmen auf /
If the accession number is not yet known on the date of filing, for the depositary institution and the depositor's identification reference(s) (number, symbols, etc.) see the application's technical documents on /
Si le numéro d'ordre n'est pas encore connu à la date de dépôt, l'autorité de dépôt et la (les) référence(s) d'identification (numéro ou symboles etc.) du déposant figurent dans les pièces techniques de la demande, à la/aux

Seite(n) / page(s)	*Zeile(n) / line(s) / ligne(s)*

☐ Die Angaben werden später mitgeteilt / The information will be submitted later / Les indications visées seront communiquées ultérieurement

34.2 Die Empfangsbescheinigung(en) der Hinterlegungsstelle / The receipt(s) of deposit issued by the depositary institution / Le(s) récépissé(s) de dépôt délivré(s) par l'autorité de dépôt

☐ ist (sind) beigefügt. / is (are) enclosed. / est (sont) joint(s).

☐ wird (werden) nachgereicht. / will be filed later. / sera (seront) produit(s) ultérieurement.

Zeichen des Anmelders / Applicant's reference / Référence du demandeur: EP15/10/2010

35 Falls das biologische Material nicht vom Anmelder, sondern von einem Dritten hinterlegt wurde /
If the biological material was deposited by a person other than the applicant /
Lorsque la matière biologique a été déposée par une personne autre que le demandeur

Name und Anschrift des Hinterlegers / Name and address of depositor / Nom et adresse du déposant

35.1 Ermächtigung nach Regel 31 (1) d) /
Authorisation under Rule 31(1)(d) /
L'autorisation prévue à la règle 31(1)d)

☐ ist beigefügt / is attached / est jointe ☐ wird nachgereicht / will be supplied later / sera produite ultérieurement

36 Verzicht auf die Verpflichtung des Antragstellers nach Regel 33 (2) in gesondertem Schriftstück /
Waiver of the right to an undertaking from the requester pursuant to Rule 33(2) attached /
Renonciation, sur document distinct, à l'engagement du requérant au titre de la règle 33(2)

☐

37 Gemäß Regel 32 (1) erklärt der Anmelder hiermit, dass der Zugang zu dem in den Feldern 34 und 35 genannten biologischen Material nur durch Herausgabe einer Probe an einen Sachverständigen hergestellt wird. /
The applicant hereby declares under Rule 32(1) that the biological material referred to in Sections 34 and 35 is to be made available only by the issue of a sample to an expert. /
Conformément à la règle 32(1), le demandeur déclare par la présente que l'accessibilité à la matière biologique mentionnée aux rubriques 34 et 35 ne peut être réalisée que par la remise d'un échantillon à un expert.

☐ BIOM 3

38 Nucleotid- und Aminosäuresequenzen / Nucleotide and amino acid sequences / Séquences de nucléotides et d'acides aminés

SEQL 1

38.1 Die Beschreibung enthält ein Sequenzprotokoll auf Papier nach Regel 30 (1). /
The description contains a sequence listing on paper in accordance with Rule 30(1). /
La description contient un listage de séquences sur papier conformément à la règle 30(1).

☐ ☐ wird nachgereicht / will be supplied later / sera produite ultérieurement

38.2 Eine Kopie des in Feld 38.1 genannten Sequenzprotokolls auf einem elektronischen Datenträger ist beigefügt. /
A copy of the sequence listing referred to in Section 38.1 on an electronic data carrier is enclosed. /
Une copie du listage de séquences mentionné à la rubrique 38.1 est jointe sur un support électronique de données.

☐

38.3 Der Anmelder erklärt hiermit, dass die auf dem elektronischen Datenträger gespeicherte Information mit dem auf Papier eingereichten Sequenzprotokoll übereinstimmt. /
The applicant hereby states that the information recorded on the electronic data carrier is identical to the sequence listing filed on paper. /
Il est déclaré par la présente que l'information figurant sur le support électronique de données est identique à celle que contient le listage de séquences déposée sur papier.

☐

Sonstige Angaben / Further indications / Indications supplémentaires

39 Zusätzliche Abschriften der im europäischen Recherchenbericht angeführten Schriftstücke werden beantragt. /
Additional copies of the documents cited in the European search report are requested. /
Prière de fournir des copies supplémentaires des documents cités dans le rapport de recherche européenne.

Anzahl der zusätzlichen Sätze von Abschriften / Number of additional sets of copies / Nombre de jeux supplémentaires de copies

ASOC

40 Die Rückerstattung der Recherchengebühr gemäß Artikel 9 (2) Gebührenordnung wird beantragt. /
Refund of the search fee under Article 9(2) of the Rules relating to Fees is requested. /
Le remboursement de la taxe de recherche est demandé en vertu de l'article 9(2) du règlement relatif aux taxes.

☐

41 Eine Kopie des Recherchenberichts ist beigefügt. /
A copy of the search report is attached. /
Une copie du rapport de recherche est jointe.

☐

Zeichen des Anmelders / Applicant's reference / Référence du demandeur: EP15/10/2010

42 **Automatischer Abbuchungsauftrag / Automatic debit order / Ordre de prélèvement automatique**

DECA

(nur möglich für Inhaber von beim EPA geführten laufenden Konten) / (for EPO deposit account holders only) / (possibilité offerte uniquement aux titulaires de comptes courants ouverts auprès de l'OEB)

Das EPA wird hiermit beauftragt, fällig werdende Gebühren und Auslagen nach Maßgabe der Vorschriften über das automatische Abbuchungsverfahren vom nebenstehenden laufenden Konto abzubuchen. /
The EPO is hereby authorised, under the Arrangements for the automatic debiting procedure, to debit from the deposit account opposite any fees and costs falling due. /
Par la présente, il est demandé à l'OEB de prélever du compte courant ci-contre les taxes et frais venant à échéance, conformément à la réglementation relative à la procédure de prélèvement automatique.

Nummer des laufenden Kontos / Deposit account number / Numéro du compte courant

Name des Kontoinhabers / Account holder's name / Nom du titulaire du compte

43 Etwaige **Rückzahlungen** sollen auf das nebenstehende beim EPA geführte laufende Konto erfolgen. /
Any **refunds** should be made to the EPO deposit account opposite. /
Les **remboursements** éventuels doivent être effectués sur le compte courant ci-contre ouvert auprès de l'OEB.

Nummer des laufenden Kontos / Deposit account number / Numéro du compte courant

DEPA

Name des Kontoinhabers / Account holder's name / Nom du titulaire du compte

44 Die vorgeschriebene Liste über die diesem Antrag beigefügten Unterlagen ergibt sich aus der vorbereiteten Empfangsbescheinigung (Seite 8 dieses Antrags). /
The prescribed list of documents enclosed with this request is shown on the prepared receipt (page 8 of this request). /
La liste prescrite des documents joints à la présente requête figure sur le récépissé préétabli (page 8 de la présente requête).

☒

45 Für Angestellte nach Artikel 133 (3) Satz 1 mit allgemeiner Vollmacht /
For employees under Article 133(3), first sentence, having a general authorisation /
Pour les employés mentionnés à l'article 133(3), 1ère phrase, munis d'un pouvoir général

Nummer / Number / Numéro

46 **Unterschrift(en) des (der) Anmelder(s) oder Vertreter(s)**
Name des (der) Unterzeichneten bitte in Druckschrift wiederholen und bei juristischen Personen die Stellung des (der) Unterzeichneten innerhalb der Gesellschaft angeben. /
Signature(s) of applicant(s) or representative(s)
Under signature please print name and, in the case of legal persons, position within the company. /
Signature(s) du (des) demandeur(s) ou du (des) mandataire(s)
Prière d'indiquer en caractères d'imprimerie le ou les noms des signataires ainsi que, s'il s'agit d'une personne morale, la position occupée au sein de celle-ci par le ou les signataires.

Ort / Place / Lieu

BARCELONA

Datum / Date

15/10/2010

Unterschrift(en) / Signature(s)

Xavier Gil Mur
Vicerector de Política Científica

Zeichen des Anmelders / Applicant's reference / Référence du demandeur: EP15/10/2010

Europäisches Patentamt
European Patent Office
Office européen des brevets

Empfangsbescheinigung
Receipt for documents
Récépissé de documents

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47 **A. Anmeldungsunterlagen und Prioritätsbeleg(e) / Application and priority documents / Pièces de la demande et document(s) de priorité**

			Blattzahl / Number of sheets* / Nombre de feuilles**
1.	Beschreibung (ohne Sequenzprotokollteil) / Description (excluding sequence listing part) / Description (sauf partie réservée au listage des séquences)	☒	17
2.	Patentansprüche / Claims / Revendications	☒	3
3.	Zeichnung(en) / Drawing(s) / Dessin(s)	☒	8
4.	Sequenzprotokollteil der Beschreibung / Sequence listing part of description / Partie de la description réservée au listage des séquences	☐	
5.	Zusammenfassung / Abstract / Abrégé	☒	1
6.	Früher eingereichte Anmeldung / Previously filed application / Demande déposée antérieurement	☐	
7.	Übersetzung der Anmeldungsunterlagen / Translation of the application documents / Traduction des pièces de la demande	☐	
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9.	Prioritätsbeleg(e) / Priority document(s) / Document(s) de priorité	☐	*Anzahl / Number / Nombre**:
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EP15/10/2010

48 **B. Der Anmeldung in der eingereichten Fassung liegen folgende Unterlagen bei: / This application as filed is accompanied by the items below: / Les pièces ci-après sont annexées à la présente demande :**

1.	Vollmacht / Authorisation / Pouvoir	☐
2.	Allgemeine Vollmacht / General authorisation / Pouvoir général	☐
3.	Erfindernennung / Designation of inventor / Désignation de l'inventeur	☐
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49 **C. Exemplare dieser Empfangsbescheinigung** (bitte zutreffende Zahl ankreuzen) / **Copies of this receipt for documents** (please mark appropriate number with a cross) / **Exemplaires du présent récépissé de documents** (veuillez cocher le chiffre correspondant)

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EPA/EPO/OEB 1001.8 10.10

A method of measuring a displacement-related parameter using a laser self-mixing measuring system, and a laser self-mixing measuring system

Field of the art

The present invention generally relates, in a first aspect, to a method of measuring a displacement-related parameter using a laser self-mixing measuring system, and more particularly to a method which comprises moving a laser facing a target and using a second laser facing said moving laser to monitor it and thus provide an output reference signal.

A second aspect of the invention concerns to a laser self-mixing measuring system, and more particularly to a system capable or carrying out the method of the first aspect.

Prior State of the Art

There are several proposals related to using a laser self-mixing measuring system for measuring a displacement-related parameter, such as relative motion, relative velocity or relative distance of an object, from a laser emitting a light beam onto said object, and there are also different applications for such systems.

Next patent documents disclose some of said proposals for a variety of applications, and can be considered as the prior art to the present invention.

International application WO2009153699A1 relates to a driver assistance system for assisting a driver of a vehicle with parking the vehicle, wherein the driver assistance system comprises one or more lasers each having a laser cavity for emitting a first light beam which is to be reflected by an object, wherein the first light beam and the reflected light beam interfere within the laser cavity. The driver assistance system further comprises a detector for detecting the interference within the laser cavity and a determination unit for determining the relative velocity as well as the relative distance between the driver assistance system and the object on the basis of the interference within the laser cavity. An assisting unit assists the driver of the vehicle with parking the vehicle on the basis of at least one of the determined relative velocity and the determined relative distance.

In WO2009153699A1 said relative distance and relative velocity is determined from first and second beat frequencies detected when a first frequency of the first laser beam is maintained constant, increased and/or decreased, depending on the interference in the laser cavity.

No other method for determining said displacement-related parameters, i.e. distance and relative velocity, is disclosed by WO2009153699A1.

US7283214B2 relates to a self-mixing laser range finder that includes a laser and a photosensitive element. As usual in this kind of systems, the laser projects a beam onto a target surface, and a backscattered portion of the laser beam returns to the laser from the target surface and enters the laser emitting cavity. Variations in laser output power are detected by the photosensitive element, which provides a "beat" signal to a frequency detection circuit. The frequency detection circuit includes a difference frequency analogue phase locked loop (DFAPLL) providing a purified form of the beat signal. The frequency of the purified beat signal is determined and used to calculate distance to the target surface.

US7283214B2 does not disclose any other method for determining said relative distance than the one comprising using said beat signal frequency.

WO2010004478A2 discloses a laser self-mixing measuring device comprising a laser with a laser cavity and a surface arranged along the optical path of the laser beam which redirects incident laser light back into the laser cavity. The device comprises a monitoring device for monitoring the laser intensity or a parameter equivalent thereto, and detection circuitry for detecting periodic changes of the laser intensity monitored by the monitoring device. The surface is part of a diffractive movable element and comprises a periodic structure which diffracts the incident laser light into partial beams.

The purpose of the diffractive element provided by WO2010004478A2 is to evenly reflect the incident laser light back into the laser cavity, thereby eliminating or at least considerably suppressing speckle-related phenomena.

For an embodiment WO2010004478A2 the device comprises two lasers emitting two respective light beams on a diffractive grating in two different lateral directions.

No other method apart from that related to analysing the output power of the laser is disclosed by WO2010004478A2, nor about providing some embodiment including lasers which are not facing the target, i.e. which have another purpose.

US5808743 relates to a sensor to measure target position, velocity and vibration based on optical feedback-induced fluctuations in the operating frequency of a diode laser. The sensor comprises a diode laser, an optical frequency discriminator to measure the laser operating frequency, and an electronic signal analyzer to obtain the modulation frequency of the laser operating frequency.

The sensor of US5808743 further includes two calibration mechanisms for vibration amplitude measurement. In a first calibration mechanism, in order to isolate the effects of target vibration the diode laser is mounted on a laser vibrator which vibrates the laser relative to the target, with a calibrated amplitude and frequency.

No mention is done in US5808743 about using said laser vibrator for other purposes other than said related to said calibration mechanism.

US7492351B2 discloses a computer cursor control device which, for an embodiment, uses laser interferometry to detect the movement of cursor control device relative to a stationary surface. A semiconductor laser diode emits light onto a beam-splitter, which divides light into a reference beam and a measurement beam which are reflected back along the same path by a movable mirror and stationary surface, respectively. Beam-splitter then recombines the two beams and directs the heterodyned beam onto a photodiode. The Doppler effect causes a frequency change of the light reflected from stationary surface when cursor control device is moving. Consequently, the heterodyne beam detected by photodiode oscillates in time at a frequency indicative of the speed of the cursor control device.

To determine the direction in which the cursor control device is moving, said movable mirror is mounted on an actuator, such as a PZT or a MEMS actuator, that moves mirror to increase or decrease the optical path of reference light. This in turn causes the phase modulation of the light that creates a beat frequency that increases or decreases according to the direction the cursor control device is moving.

The two beams provided by the US7492351B2 come always from the same laser diode, and there is not disclosed therein to use the two beams generated for purposes other than those described above.

None of the cited proposals disclose measuring a displacement-related parameter using a laser self-mixing measuring system, by comparing or operating two interferometric signals: the conventional one generated by a first laser aiming a target and a reference signal generated by another laser aiming the first laser.

Description of the Invention

It is necessary to offer an alternative to the state of the art which covers the gaps found therein and which provides such an, until now, unknown proposal.

To that end, the present invention provides, in a first aspect, a method of measuring a displacement-related parameter using a laser self-mixing measuring system, the method comprising, in a known manner, the steps of:

a) emitting a first light beam onto an, at least in part reflective, object, with a laser having a laser cavity;

b) receiving back into said laser cavity light, of said first light beam, reflected onto said object, said laser cavity changing, upon said light reception, its resonance properties, which causes said first light beam properties also to change;

c) detecting values of one or more parameters of said first light beam, or of the interior of said laser cavity, at least once their properties have changed; and

d) determining the relative motion and/or relative velocity and/or relative distance of said object, with respect to said laser, from at least the detected values of said at least one parameter.

The method of the first aspect of the invention differs from the prior art methods, in a characteristic manner, in that said laser is a first laser, and in that the method comprises:

- moving said first laser while emitting said first light beam;

- emitting a second light beam onto a moving reflective surface of said first laser or of a support thereof, with a second laser having a laser cavity;

- receiving back into said second laser cavity light, of said second light beam, reflected onto said moving reflective surface, said second laser cavity changing, upon said light reception, its resonance properties, which causes said second light beam properties also to change; and

- detecting values of one or more parameters of said second light beam, or of the interior of said second laser cavity, at least once their properties have changed.

And in that said step d) comprises determining at least the relative motion and/or relative velocity and/or relative distance of said object, with respect to said first laser, by comparing and/or operating the detected values of said first and second light beams parameters, or of first and second signals generated therefrom.

For an embodiment said parameters relate to optical output power, although for other embodiments they are other kind of parameters whose values change upon receiving back into the respective laser cavity the reflected light beam

For the embodiments in which step d) is done on said first and second signals generated from the first and second light beams parameters, said first and second signals vary along time, and the detected values represent the magnitude variation along time of the first and second signals.

According to an embodiment of the method of the first aspect of the invention, said comparison or operation of the first and second signals of step d) is carried out in order to look for differences between both signals, said differences between both signals relating, for a preferred embodiment, to relative displacements of transition points between both signals. Said transition points are generally half-wavelength transition points.

As said first and second signals could have different origins which would false the measures regarding said relative displacement, the method of the first aspect of the invention comprises synchronizing the start points of the first and second signals before looking for said relative displacements.

For an embodiment, said step d) comprises reconstructing a motion perturbance undergone by said object by operating said transition points relative displacements.

The method comprises, for some embodiments, moving the first laser according to an oscillating pattern having any appropriate time shape, such as a time sinusoidal shape and a time triangular shape.

A second aspect of the invention concerns to a laser self-mixing measuring system comprising, in a known manner:

- a laser having a laser cavity and arranged for emitting a first light beam onto an, at least in part reflective, object, and for receiving light, of said first light beam, reflected onto said object back into said laser cavity which, upon said light reception, changes its resonance properties which makes said first light beam to change its properties;

- detection means arranged for detecting values of at least one parameter of said first light beam, or of the interior of said laser cavity, and

- measuring means, connected to said detection means, and intended for determining the relative motion and/or relative velocity and/or relative distance of said object, with respect to said laser, from at least the detected values of said at least one parameter.

The laser self-mixing measuring system provided by the second aspect of the invention differs, in a characteristic manner, from the conventional systems in that:

- said laser is a first laser which is moveable,

- said laser self-mixing measuring system also comprises a second laser having a laser cavity and arranged to emit a second light beam onto a reflective surface of said first laser or of a support thereof, and for receiving light, of said second light beam, reflected onto said reflective surface back into said laser cavity which, upon said light reception, changes its resonance properties which makes said second light beam to change at least part of its properties;

- said detection means are arranged also for detecting values of at least one parameter of said second light beam, or of the interior of said second laser cavity, and in that

- said measuring means are intended for determining at least the relative motion and/or relative velocity and/or relative distance of said object, with respect to said first laser, by comparing and/or operating the detected values of said at least two first and second light beams parameters or of first and second signals generated therefrom.

For some embodiments the first laser is mounted on said support, which is moveable by the action of a driving mechanism, which, for an embodiment comprises at least one electrically excited vibrating element fixed or at least in contact with said support, and electronic means supplying said vibrating element with electrical signals predetermined for making it vibrate according to a predetermined oscillation.

Said electrically excited vibrating element is, for an embodiment, one of a piezoelectric element and a voice coil.

The electronic means comprise an exciting unit for supplying said electrical signals to said vibrating element, said exciting unit being, for some embodiments, intended for supplying the vibrating element with electrical signals with a predetermined oscillation, such as a sinusoidal electrical signal, a square electrical signal or a triangular electrical signal.

The method and system of the invention are valid for several kinds of lasers, depending on the embodiment, but there are two commercially relevant ones which are called horizontal cavity lasers / Fabry Perot (FP) cavity lasers and vertical cavity lasers / VCSELs, having the latter a more stable behaviour, which makes them to be more preferred to be used to implement the present invention.

As for the detection means is concerned, for an embodiment, they comprise two respective photodiodes detecting the laser light within or outside the laser cavities.

For other embodiments of the system of the second aspect of the invention, it comprises a plurality of first lasers emitting respective light beams onto said object, movable in conjunction or independently from each other, and a plurality of second lasers emitting respective second light beams onto said first lasers or supports thereof, the detection means being arranged also for detecting values of said plurality of first and second light beams, or of the interior of their cavities, and the measuring means being intended for determining the relative motion and/or relative velocity and/or relative distance of the object, with respect to said first lasers, by comparing and/or operating the detected values of part or all of said plurality of first and second light beams parameters or of first and second signals generated therefrom.

For some embodiments part or all of the system of the second aspect of the invention is integrated in an integrated circuit.

Said integrated circuit comprises, for one of said embodiments, the first and second lasers and the detection means, while for other embodiments the integrated circuit comprises more or less components of the system of the second aspect of the invention.

Brief Description of the Drawings

The previous and other advantages and features will be more fully understood from the following detailed description of embodiments with reference to the attached drawings, which must be considered in an illustrative and non-limiting manner, in which:

Figure 1 shows, schematically and for an embodiment, the system of the second aspect of the invention, which components will be described in detail in the next section;

Figure 2 shows two respective waves of the first and second signals corresponding to the detected parameter values of the first and second light beams emitted by, respectively, the first and second lasers of the system of the second aspect of the invention, according to the method of the first aspect;

Figure 3 shows several waves, obtained from a simulation, and corresponding to an embodiment of the method of the first aspect, where the first laser has been moved according to a sinusoidal oscillation, and a rough technique has been used to reconstruct the perturbance undergone by a target;

Figure 4 also shows several waves, also obtained from a simulation, and corresponding to another embodiment of the method of the first aspect, where the first laser has been moved according to a triangular oscillation and also a rough technique has been used to reconstruct the perturbance;

Figure 5 shows waves corresponding to another simulation, as an embodiment of the method of the first aspect, where the first laser has been moved also according to a triangular oscillation but a linear approximation technique has been used to reconstruct the perturbance;

Figure 6 shows waves corresponding to a simulation similar to the one of Figure 5, but differentiated there from in that the perturbance undergone by target is a Sine perturbance;

Figure 7 show several graphs corresponding to experimental measurement results obtained from a prototype implementing the system of the second aspect of the invention, for a static target; and

Figures 8a, 8b and 8c show, by means of several graphs, the measurement results, for a known-movement target, obtained from the same prototype of Figure 7.

Detailed Description of Several Embodiments

Figure 1 shows the system of the second aspect of the invention for a basic embodiment, comprising the next described elements.

A first laser LD1 is arranged for emitting a first light beam be1 onto target or object T, and for receiving reflected light beam br1, and is mounted on a support S which is moved according to the oscillation with the known shape O and the direction of the arrows drawn in Figure 1, by means of an electrically excited vibrating element V, such as a piezolectric element, attached thereto, supplied with electrical signals by an exciting unit of electronic means Em. For another embodiment, not shown, a voice coil is used instead of said piezoelectric element.

A second laser LD2 is fixedly arranged to emit a second light beam be2 onto a reflective surface of the support S of the first laser LD1, and for receiving reflected light beam br2.

Detection means Dm1, Dm2, such as photodiodes, are arranged for detecting the output optical power of, respectively, the first light beam be1 and the second light beam be2. The detected signals are illustrated in Figure 2, for an embodiment, indicated as LD2 signal and LD1 signal.

With the illustrated arrangement, LD2 is monitoring LD1 oscillation O, and therefore the signal emitted by LD2, detected by Dm2, is considered as a reference self-mixing signal.

However, for a stationary target T both lasers LD2, LD1 emit equal light beams, and therefore Dm1 and Dm2 detect equal corresponding signals. Obviously, by applying any unknown displacement to the target, LD1 will present a different self-mixing signal than said LD2 reference signal.

The shape of said unknown displacement, or perturbance, is illustrated in Figure 1 indicated as P. The aim is to reconstruct the unknown displacement P out of the two detected signals from LD2 and LD1, what is done by comparing and/or operating them according to the method of the first aspect of the invention described in a previous section.

Figure 1 also show measuring means M, connected to detection means D, and intended for determining the relative motion and/or relative velocity and/or relative distance of target or object T, with respect to first laser LD1, from the detected LD2 and LD1 signals, corresponding to the output optical power detected values.

Said measuring means M are intended for carrying out said determination of the relative motion and/or relative velocity and/or relative distance of said object T, in the case illustrated to determine or reconstruct perturbance P, by doing said comparison and/or operation of LD2 and LD1 signals, coming from, respectively, first be1 and second be2 light beams.

For the embodiment illustrated by Figure 1, said measuring means M are connected to the electronic means Em, in order to allow its access to information related to Em operation which could be used to carry out said determination, such as information related to the oscillation O.

For some embodiments of the system provided by the second aspect of the invention, more elaborated that the one illustrated by Figure 1, it also comprises a resolution improver device (not shown), which comprises one or more modulator devices placed in front of the first laser LD2 and/or of the second laser LD1, connected to the measurement means M, or to another electronic system.

Said modulator device is capable of changing, in a controlled manner, the phase of the light wave entering there in, and depending on the embodiment comprises one or more of an electro-optical modulator, an acousto-optical modulator, a magneto-optical modulator, a liquid crystal spatial light modulator (SLM), and a modulator of another type, such as those based on solid crystals which refractive index is changed upon applying some external function as a voltage.

The method and the system of the invention comprise associating the one or more modulator devices to phase shifting algorithms (implemented in the system by said measurement means M or said electronic system) which provide an improved resolution of the perturbance P reconstruction by accurately determining the phases of the light waves by means of intensity measures taken there from.

In order to ensure that all interference signals, from LD2 and LD1, are as identical as possible, the method and the system of the invention comprise, for different embodiments, one or more of the next issues, in the form of actions, when referring to the method, and hardware and/or software elements, when referring to the system:

- a mechanism for controlling/compensating the wavelength of the lasers LD1 and LD2 signals, to make it to be as similar as possible in the two lasers LD1, LD2. A way to carry it out includes measuring several lasers and taking the two which most resemble to each other, plus compensating, for example by means of software, for the low frequency residual waves remaining in the signals. Another alternative or complementary way for equalling the wavelengths of both laser signals includes the use of interferential filters.

- a mechanism for controlling/compensating the temperature of the lasers (which changes their wavelength). Usually that is done with a Peltier element (as it usually comes in the marketed lasers), but there are mechanisms more sophisticated which are used for more elaborated embodiments of the invention.

- a mechanism for compensating/controlling the difference in the start points of LD1 and LD2 signals, when said signals have different origins. For some embodiments said mechanism operates by manipulating the lasers feedback conditions, such as by adjusting the focusing of the beams with some active optical elements, like a liquid lens, or by adjusting the feedback level with some variable intensity attenuator.

- a mechanism for correcting/compensating deviations from the expected/ideal electrical signal supplying the piezoelectric element V. The nature, magnitude and form of said deviations vary depending on the type and shape of the electrical signal used. For example, where said electrical signal is of a triangular shape, which although offers better results than those achieved with sinusoidal supplying signals (as will be disclosed later with reference to Figures 3 and 4), as the sampling is uniform, it has the drawback that the real signal is rounded to the "tips" because of electronic noise matters, and thus said real signal is deviated from the expected/ideal electric signal. Said mechanism is arranged for correcting/compensating any kind of deviations caused by whatever the type and shape of the electrical signal used for said supplying of the piezoelectric element V.

- a mechanism for correction/compensation of hysteresis in the electrically excited vibrating element V displacing support S, particularly when using piezoelectric crystals, which usually have hysteresis, and when the supplying electric signal is of a triangular shape the movement provided by the piezoelectric element V is not really triangular. For an embodiment said mechanism comprises a circuit for feeding the piezoelectric element V in closed loop with a capacitive sensor, or working with other kind of electrically excited vibrating elements with less hysteresis, such as the above mentioned voice coil.

- a mechanism for compensation of mechanical vibrations, which, for a basic embodiment, comprises to provide an anti-vibratory table to support the system, while for other more accurate embodiment, said mechanism comprises accelerometers, built in MEMS, placed beside the laser to measure vibrations and then subtract them from the output signal.

Obviously, power supply and amplifier circuits (not shown), other components of the system and lasers must be as identical as possible to ensure maximum similarity between the signals obtained there from.

According to the method of the invention, a proposed technique for extracting the unknown displacement, or perturbance P, from LD2 and LD1 signals is comparison of the transitions positions in both signals. Figure 2 shows two relative displacements d1, d2 caused at two respective transition points of LD1 signal with respect to LD2 signal, transition points which positions are displaced because the displacement P of object T only affects LD1 signal.

On contrary to what is illustrated in Figure 2, LD2 and LD1 signals usually have different origins, i.e. different start points. In order to obtain said signals, the method of the first aspect of the invention comprises the above indicated mechanism for compensating the start point of LD2 and LD1 signals, in other words the method comprises synchronizing the start points of said LD2 and LD1 signals before looking for said relative displacements d1, d2.

Said start points synchronizing is carried out by the system of the second aspect of the invention by means of software and/or hardware based algorithms implemented in measuring means M.

According to the method of the first aspect of the invention, at first, simple transition detection is used to determine the position of the transitions for both LD2 and LD1 signals, and then relative displacement of the transitions for each transition is calculated, i.e. d1, d2 are calculated. In fact, positive and negative value of transitions displacement d1, d2, corresponding to the direction of the displacement is considered in the processing, so in this technique there is no direction ambiguity.

Resolution of the measurement is affected by the acquisition rate, the precision of the transition position detection and signal to noise ratio of the sensors used comprised by detection means Dm1, Dm2. Moreover, number of transition per second (NT) or sampling rate depends on the amplitude and the frequency of the known oscillation O as the following:

$$NT= (4a/\lambda).f \quad (1)$$

Where a is peak to peak amplitude of the oscillation, λ is the laser wavelength and f is the frequency of the oscillation.

According to an embodiment of the method of the invention, after transitions detection of both self-mixing signals, i.e. LD2 and LD1 signals, transitions positions for each of said two signals are separately calculated. In this step, two array are defined for this purpose as trans_pos1[n] and trans_pos2[n] where n is the number of transition. When trans_pos1[3]=543, it means that in LD2 signal the 3^{rd} transition happens at the position of 543 in the acquired sequence of the data. Then by comparing the transition positions of both self-mixing signals, the perturbance P amplitude at each transition position can be obtained. Consequently, the perturbance amplitude is considered:

$$Perturbation\_amp = \left(\frac{\lambda}{2}\right) \times \frac{trans\_pos2[i] - trans\_pos1[i]}{trans\_pos1[i] - trans\_pos1[i-1]} \quad (2)$$

It should be noted that the transition displacements (d1 and d2 in Figure 2) are calculated relatively to the reference laser (LD2) transitions. From relation (2), perturbance amplitude can be easily calculated, according to different reconstruction techniques which will be explained later.

Figures 3 and 4 present the results, and wave shapes used, regarding two simulations of the method of the invention, for two respective embodiments, differentiated between them by the shape of oscillation O, which corresponds to the shape of the electrical signals supplying the piezolectric element P. In Figure 3 oscillation O has a sinusoidal shape, while in Figure 4 it has a triangular shape.

For both simulations, peak to peak amplitude of the oscillation O is 20 λ, frequency of oscillation O is 100Hz, sampling rate (for transitions) is 4 kHz, perturbance P length is 3.3ms and simulation sampling (corresponds signal acquisition rate) was 210000 points per period.

From top to bottom of Figures 3 and 4, next waves, varying along time, are illustrated therein:

- Perturbance P, measured as per the displacement, in meters, it causes on target O.

- Oscillation O, also measured in meters.

- Transitions detected for LD2, i.e. transitions detected in LD2 signal, measured in a normalized OOP (output optical power).

- Transitions detected for LD1, i.e. transitions detected in LD1 signal, also measured in a normalized OOP.

- Perturbance P reconstruction, measured as per a reconstructed displacement, in meters, from the comparison of transitions for LD2 and LD1 signals.

- Reconstruction error, measured in meters, and obtained by subtracting the original displacement of perturbance P to the reconstructed displacement.

Regarding said reconstruction error, simulations of Figure 3 give an Average Error of 2.23 nm and a Maximum Error of 11.2 nm, while simulations of Figure 4 give an Average Error of 3.28 nm and a Maximum Error of 10 nm.

Other simulations, which results are not drawn in appended Figures, were done for both a sinusoidal and a triangular oscillation O, with an oscillation O peak to peak amplitude of 160 λ, an oscillation O frequency of 100Hz and a sampling rate of 32 kHz considered. Perturbance P length and simulation sampling were the same than the ones used for Figures 3 and 4.

The result of both of said simulations gave an Average Error of 0.58 nm and a Maximum Error of 2.38 nm, for the sinusoidal oscillation O, and an Average Error of 0.59 nm and a Maximum Error of 2.37 nm.

By exciting the LD1 triangularly, as it is shown in Figure 4, the transitions distribution in the whole period (sampling) is uniform, while in sinusoidal excitation (Figure 3), transitions distribution density along the period is not uniform (i.e. at peaks positions less transitions than at the middle of oscillation). As it can be deduced from the results given by said simulations, for triangular excitation (uniform sampling) maximum error is always smaller than the sinusoidal, however the mean error for sinusoidal excitation is smaller. But it should be noticed that perturbance P happens at an unknown moment, so it may be happen at the peaks of excitation which in this case triangular excitation will have a better resolution, and then should be a better choice, having in mind the above mentioned drawback related to the rounded tips of the real signal, which can be faced by the above indicated mechanism for correction/compensation of deviations from the electric signal supplying the piezoelectric element V.

Other four simulations, with triangular excitation, have been done using the same parameter values used for the simulation of Figure 4, with the only exception of the one related to the perturbance P amplitude, which has been chosen to be of 1nm, 25nm, 100nm and 400nm, for each of said respective four simulations.

The results obtained for said four additional simulations are the next:

- for a perturbance P amplitude of 1 nm, an Average Error of 0.08 nm and a Maximum Error of 0.15 nm have been obtained, related to the reconstruction error;

- for a perturbance P amplitude of 25 nm, an Average Error of 0.92 nm and a Maximum Error of 2.88 nm;

- for a perturbance P amplitude of 100 nm, an Average Error of 3.7 nm and a Maximum Error of 11.3 nm; and

- for a perturbance P amplitude of 400 nm, an Average Error of 14.9 nm and a Maximum Error of 41.8 nm.

From said four simulations results, it can be considered that the greater the perturbance P amplitude, the higher the reconstruction error obtained, although it should be pointed out that by using a higher sampling rate a better resolution is obtained.

The reconstruction technique used for the above described simulations, the ones illustrated and also the ones not illustrated, has been a rough or basic one which considers that as far as the distance between two transitions corresponds to a displacement of half the wavelength of the laser, the displacement is assumed to be proportional to the fraction of the distance of the two transitions which is detected. The result is a step-like reconstructed signal, as can be seen in Figures 3 and 4.

In that rough reconstruction, perturbance_amp, defined according to (2), is the function that is directly used for the perturbance reconstruction. In this technique, only the perturbance amplitude at each transition position is known, and the perturbance value for the rest of the positions (between the transitions) is considered as the same value as the perturbance amplitude in the last transition (like the staircase shape).

The resolution of the perturbance P reconstruction can be improved by using a more elaborated reconstruction technique called line fitting technique, which comprises using perturbance_amp function (2) for the perturbance amplitude at each transition position, and for the rest of the positions (between the transitions) said line fitting technique comprises fitting a line between each pair of consecutive transitions, and thus the perturbance amplitude is estimated.

For a first embodiment of said line fitting technique, the method comprises, from the step-like technique results, assuming a linear interpolation between transitions so a straight line is approximated between each of the height steps assumed.

For another embodiment of said line fitting technique, also from the step-like technique results, the method comprises applying an interpolation of an expected function shape (Gaussian, sinusoidal, etc.) to the step-like height changes.

Numerical explanation for measurement resolution

As mentioned before, resolution of the measurement is affected by the acquisition rate, the precision of the transition position detection and signal to noise ratio of the sensor of the detection means Dm1, Dm2. Besides, the number of the transitions at each acquisition (sampling rate of this method) is an important factor in the resolution of the measurement.

Considering the signal acquisition rate (i.e. oscilloscope acquisition rate or number of point at each acquisition) as NP, number of transitions per acquisition (sampling rate) as NT and $\lambda/2$ displacement for every transition, whole displacement for the acquired signal will be $(\lambda/2)*NT$. Consequently, each point of the acquisition will be $(\lambda/2)*NT/NP$.

As an example, for NP=125000 and NT=125 the resolution will be $\lambda/2000$.

This explanation is just for ideal case; without having any noise and if the transition detection precision is less than the resolution.

Figure 5 shows the results, and wave shapes used, of another simulation of the method of the invention, for an embodiment similar to the one described above (not illustrated) which was related to a perturbance P with an amplitude of 100 nm, but differentiated there from in that a linear reconstruction technique has been used to obtain the perturbance P reconstruction illustrated in Figure 5, which gives a Maximum Error of 0.001 nm, considerably better than the one obtained by a rough reconstruction technique, which was of 11.3 nm.

A similar simulation is presented in Figure 6, with the same parameter values than the ones used in the simulation of Fig. 5, but with the difference that perturbance P is a Sine perturbance, with an amplitude of 100 nm. A linear reconstruction technique has also been used to obtain the perturbance P reconstruction illustrated in Figure 6, but in this case the Maximum Error obtained has been of 0.6 nm.

Another simulation, which results are not illustrated, differentiated from the one of Figure 6 only in that the peak to peak amplitude of the triangular oscillation O is 160 λ, gave the next results: an Average Error of 0.34 nm and a Maximum Error of 1 nm.

The inventors have mounted and tested a prototype of the laser self-mixing measuring system of the invention, called by the inventors as a system using a Differential Self-mixing or Double Self-mixing Technique, and the results are shown in Figures 7 and 8a to 8c, and explained next.

There are some sources of errors in this technique or method, when being applied on the cited prototype, which should be investigated later to improve the experimental accuracy. As it has been explained before, in this system two LDs are used; one (LD1 in Figure 1) monitoring the target T movement while it is vibrating (mounted on a piezo) and the other one (LD2 in Figure 2) monitoring the vibrating LD1 displacements.

At no-target-movement status, both lasers should sense a same displacement and consequently having the same transitions positions due to the LD vibration. But, even thinking optimistically and neglecting the non-similarity of the (electrical) data acquisition of LDs, ambient mechanical noise, mechanical robustness of the system and electrical noises, there can exist some more factors affecting the accuracy of the reconstruction.

The main origins of having different transitions positions in SM signals of the lasers at no-target-movement status (error of this technique) are related to the difference of wavelength, feedback strength and line width enhancement factor in the LDs. So, adjusting the coupling factor of the both LDs for having the same coupling factor and less noise has a very important role in this technique.

Relating, for example, to feedback strength, it must be reminded that there are different degrees of laser beam feedback strength, called regimes, classified as: very weak, weak, moderate and strong. Each of said regimes gives a different signal.

Figs. 7 and 8a have been obtained for a weak feedback. If using other feedback regimes, the signals obtained may not be so clean with the transitions so well marked.

The method comprises other embodiments, for those feedback regimes which don't allow using the described transitions comparison, because they are not so well marked, to extract information related to other parameters of LD1 and LD2 signals, i.e. to carry out a different type of comparison.

The experimental results consist of two types of measurements results; one at no-target-displacement status for calculating the errors and knowing the possible errors in the measurements, with reference to Figure 7, and then, with reference to Figures 8a to 8c, measuring a known target displacement.

Figure 7 depicts the measurement results for static target T, i.e. for a perturbance P equal to zero, where "Ref. Self Mixing Signal" refers to LD2 signal, "Perturbed Self Mixing Signal" to LD1 signal, "Ref. transitions" to the transitions detected for LD2, "Perturbed transitions" to the transitions detected for LD1, and "Perturbation amplitude" to the transitions displacement graph, which is ideally expected to be zero for static target T, but, as can be seen in Figure 7, in a real case "Perturbation amplitude" is not equal to zero.

In fact, the parameters discussed above are the origin of the errors. In this measurement, vibration frequency of the LD2 is adjusted to 1Hz (triangular form) to reduce the possible mechanical noises (because all the elements of an LD package, including LD2 and associated electronics, is moving due to the vibration and consequently at high frequencies, some elements like the lens may move because they do not have a reliable connection to the LD package).

As shown in Figure 7, perturbation amplitude has DC and AC component. DC component is due to the shifted fringes positions in LD2 relative to the LD1 which may be because of wavelength, line width enhancement factor, etc. AC component, which is more important, is considered as the experimental noise for this measurement which varies between 6.1nm and 17.1nm. So it can be said that the prototype implementing the system here being tested provides an absolute error of 11nm (17.1nm-6.1nm).

Figure 8 shows the measurement results for known-movement target with a vibration of 7.5 Hz. In these measurements, vibration frequency of LD1 was 1Hz (sinus waveform). It should be noticed that the target T is a piezo actuator (without displacement sensor) which, when applying 0-10 volts at its input provides a 0-20 micron displacement. So to know the displacement P, a multiplication of the driven signal to 20μ/10v must be done to calculate the expected real displacement P. Therefore, having a difference between the calculated target displacement, indicated in Figure 8b as Pc(t), and real displacement P is unavoidable. In future tests a displacement sensor will be used to monitor the displacement P with enough accuracy.

Sensors signals (for both LDs) are shown in Figure 8a. The shown calculated target displacement Pc in Figure 8b is calculated from the driven signal (after filtered) of the piezo actuating as target T (by multiplying to 20μ/10v) which is shifted (in time) relative to the reconstructed signal P, because the piezo has a time delay for actuating (corresponding to the applied driven voltage).

As it can be seen in Figure 8c, the piezo driven signal, or T driven signal, is filtered to enable it to be compared with the reconstructed P displacements.

As shown in Figure 8b, reconstructed P displacement is very close to the calculated target displacement Pc. The minimum value of reconstructed displacement P is -117nm while the minimum of calculated target displacement Pc is -122.2nm, which provides a difference of 5.2nm. The maximum value of reconstructed displacement P is 142.4nm while the maximum calculated target displacement Pc is 149.8nm, which have a difference of 7.4nm, i.e. the difference between the maximums of the reconstructed P displacement and the estimated target displacement Pc is 7.4nm (corresponds to 2.7% error), which are very good results in presence of different types of noises.

A person skilled in the art could introduce changes and modifications in the embodiments described without departing from the scope of the invention as it is defined in the attached claims.

Claims

1.- A method of measuring a displacement-related parameter using a laser self-mixing measuring system, the method comprising the steps of:

a) emitting a first light beam onto an, at least in part reflective, object, with a laser having a laser cavity;

b) receiving back into said laser cavity light, of said first light beam, reflected onto said object, said laser cavity changing, upon said light reception, its resonance properties, which causes said first light beam properties also to change;

c) detecting values of at least one parameter of said first light beam, or of the interior of said laser cavity, at least once their properties have changed; and

d) determining the relative motion and/or relative velocity and/or relative distance of said object, with respect to said laser, from at least the detected values of said at least one parameter;

said method being **characterised** in that said laser is a first laser, and in that said method comprises:

- moving said first laser while emitting said first light beam;

- emitting a second light beam onto a moving reflective surface of said first laser or of a support thereof, with a second laser having a laser cavity;

- receiving back into said second laser cavity light, of said second light beam, reflected onto said moving reflective surface, said second laser cavity changing, upon said light reception, its resonance properties, which causes said second light beam properties also to change; and

- detecting values of at least one parameter of said second light beam, or of the interior of said second laser cavity, at least once their properties have changed;

and in that said step d) comprises determining at least the relative motion and/or relative velocity and/or relative distance of said object, with respect to said first laser, by comparing and/or operating the detected values of said at least two first and second light beams parameters, or of first and second signals generated therefrom.

2.- A method as per claim 1, wherein said first and second signals vary along time, said values representing the magnitude variation along time of said first and second signals.

3.- A method as per claim 2, wherein said comparison or operation of said first and second signals of said step d) is carried out in order to look for differences between both signals.

4.- A method as per claim 3, wherein said differences between both signals relate to relative displacements of transition points between both signals.

5.- A method as per claim 4, wherein it comprises synchronizing the start points of said first and second signals before looking for said relative displacements.

6.- A method as per claim 4 or 5, wherein said step d) comprises reconstructing a motion perturbance undergone by said object by operating said transition points relative displacements.

7.- A method as per any of previous claims, wherein it comprises moving said first laser according to an oscillating pattern.

8.- A method as per claim 7, wherein said oscillation pattern has one of a time sinusoidal shape and a time triangular shape.

9.- A laser self-mixing measuring system comprising:

- a laser (LD1) having a laser cavity and arranged for emitting a first light beam (be1) onto an, at least in part reflective, object (T), and for receiving light (br1), of said first light beam (be1), reflected onto said object (T) back into said laser cavity which, upon said light reception, changes its resonance properties which makes said first light beam (be1) to change its properties;

- detection means (Dm1, Dm2) arranged for detecting values of at least one parameter of said first light beam (be1), or of the interior of said laser cavity, and

- measuring means (M), connected to said detection means (Dm1, Dm2), and intended for determining the relative motion and/or relative velocity and/or relative distance of said object (T), with respect to said laser (LD1), from at least the detected values of said at least one parameter;

said laser self-mixing measuring system being **characterised** in that:

- said laser (LD1) is a first laser which is moveable,

- said laser self-mixing measuring system also comprises a second laser (LD2) having a laser cavity and arranged to emit a second light beam (be2) onto a reflective surface of said first laser (LD1) or of a support (S) thereof, and for receiving light (br2), of said second light beam (be2), reflected onto said reflective surface back into said laser cavity which, upon said light reception, changes its resonance properties which makes said second light beam (be2) to change at least part of its properties;

- said detection means (Dm1, Dm2) are arranged also for detecting values of at least one parameter of said second light beam (be2), or of the interior of said second laser cavity, and in that

- said measuring means (M) are intended for determining at least the relative motion and/or relative velocity and/or relative distance of said object (T), with respect to said first laser (LD1), by comparing and/or operating the detected values of said at least two first (be1) and second (be2) light beams parameters or of first and second signals generated therefrom.

10.- A laser self-mixing measuring system as per claim 9, wherein said first laser (LD1) is mounted on said support (S), which is moveable by the action of a driving mechanism.

11.- A laser self-mixing measuring system as per claim 10, wherein said driving mechanism comprises at least one electrically excited vibrating element (V) fixed or at least in contact with said support (S), and electronic means (Em) supplying said vibrating element (V) with electrical signals predetermined for making it vibrate according to a predetermined oscillation.

12.- A laser self-mixing measuring system as per claim 10, wherein said electrically excited vibrating element (V) is one of a piezoelectric element and a voice coil.

13.- A laser self-mixing measuring system as per claim 12, wherein said electronic means (Em) comprise an exciting unit for supplying said electrical signals to said vibrating element (V).

14.- A laser self-mixing measuring system as per claim 13, wherein said exciting unit is intended for supplying electrical signals with a predetermined oscillation to the vibrating element (V).

15.- A laser self-mixing measuring system as per claim 14, wherein said exciting unit is intended for supplying the vibrating element (V) with one of a sinusoidal electrical signal and a triangular electrical signal.

Abstract

A method of measuring a displacement-related parameter using a laser self-mixing measuring system, and a laser self-mixing measuring system

The method comprises:

- moving a first laser emitting a first light beam onto a target;

- emitting, by a second laser, a second light beam onto said first laser or a support thereof, to monitor it and thus provide an output reference signal; and

- determining the relative motion and/or relative velocity and/or relative distance of said target, with respect to said first laser, by comparing and/or operating the interferometry signals of both lasers, or signals depending thereon.

The system is capable or carrying out the method.

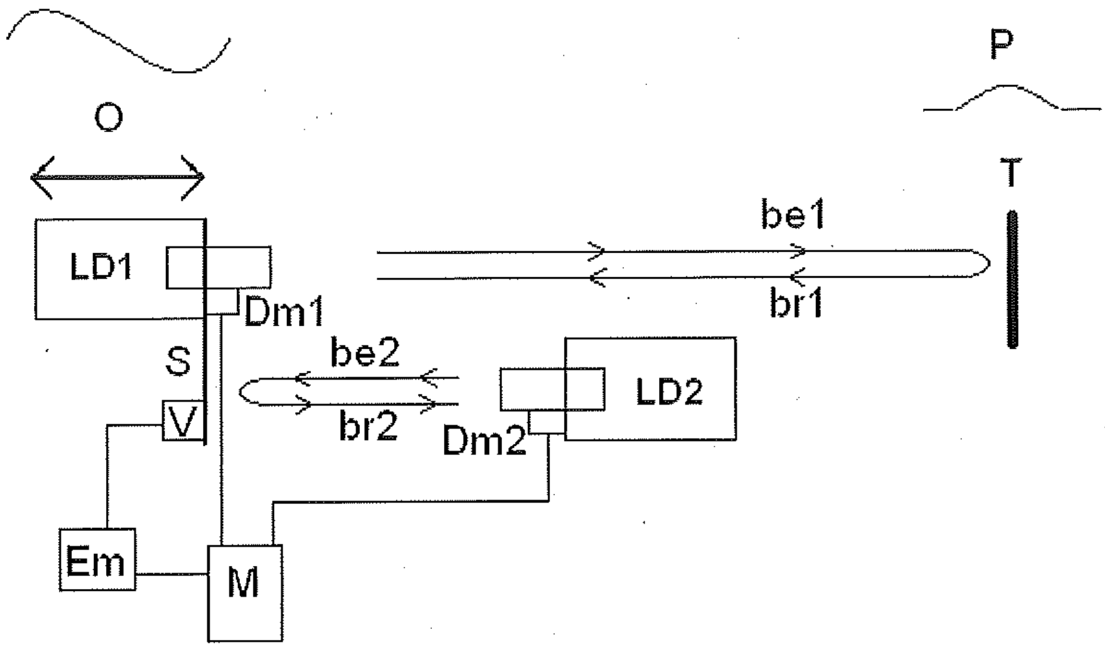


Figure 1

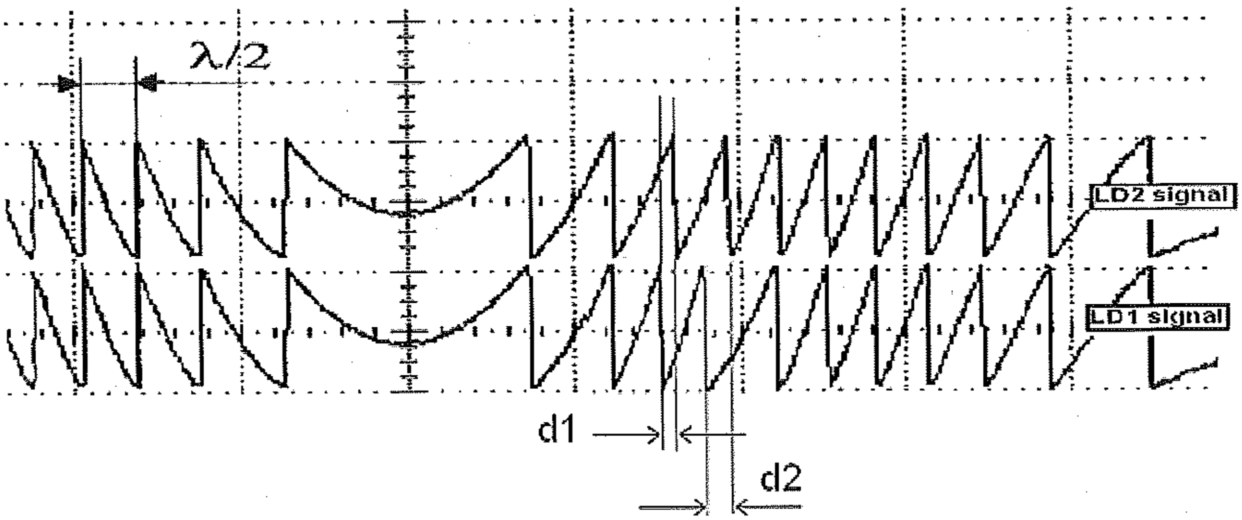
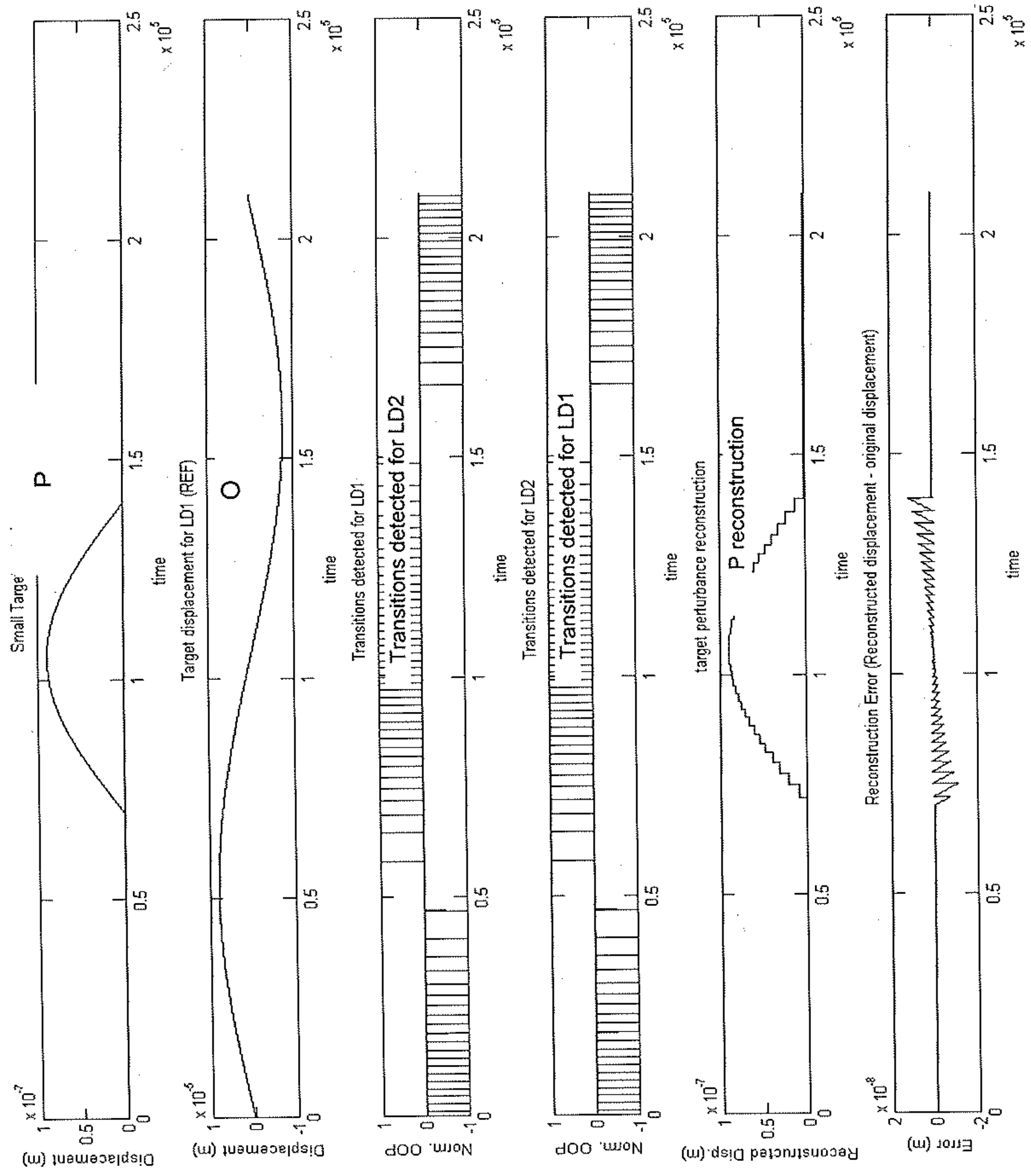


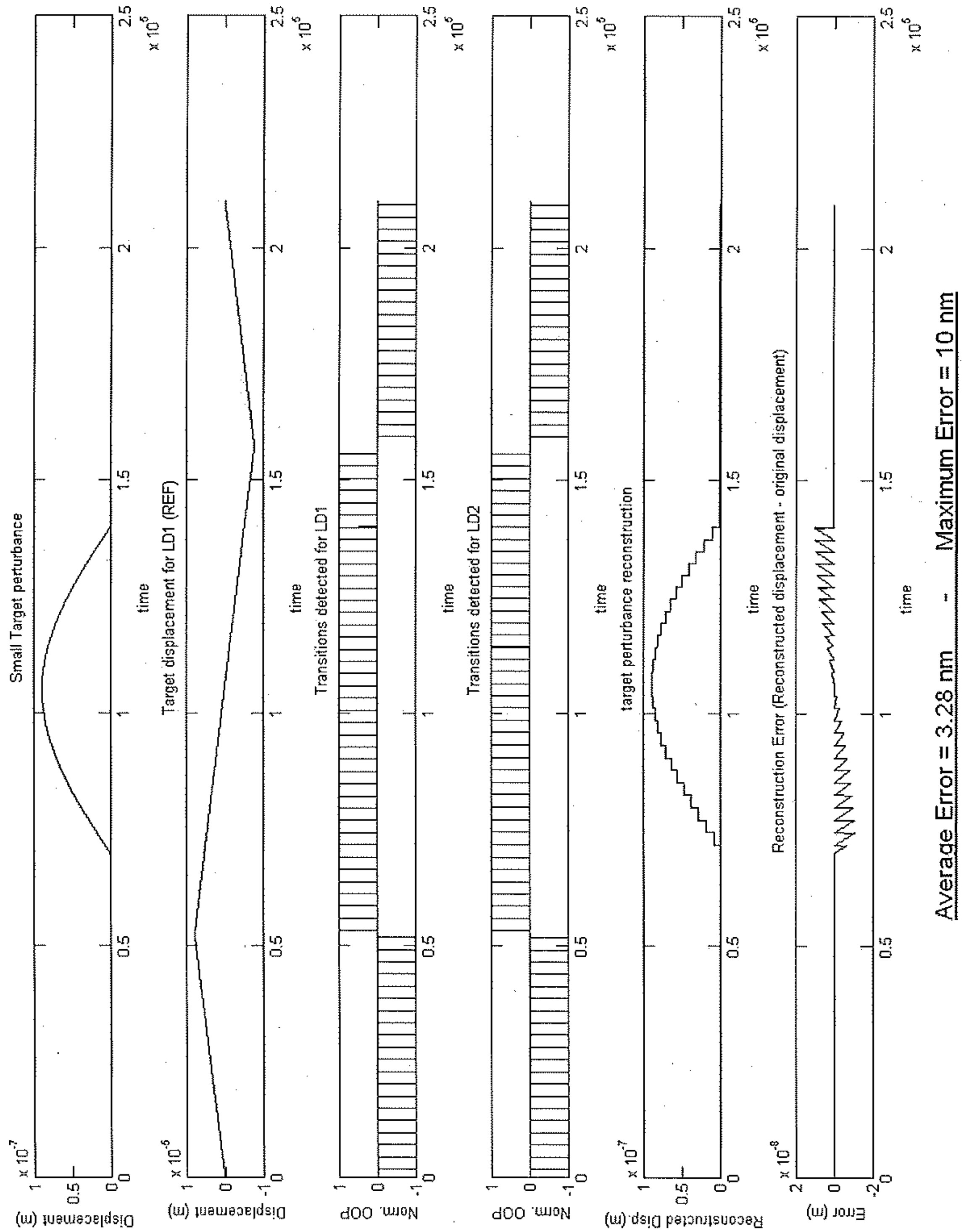
Figure 2

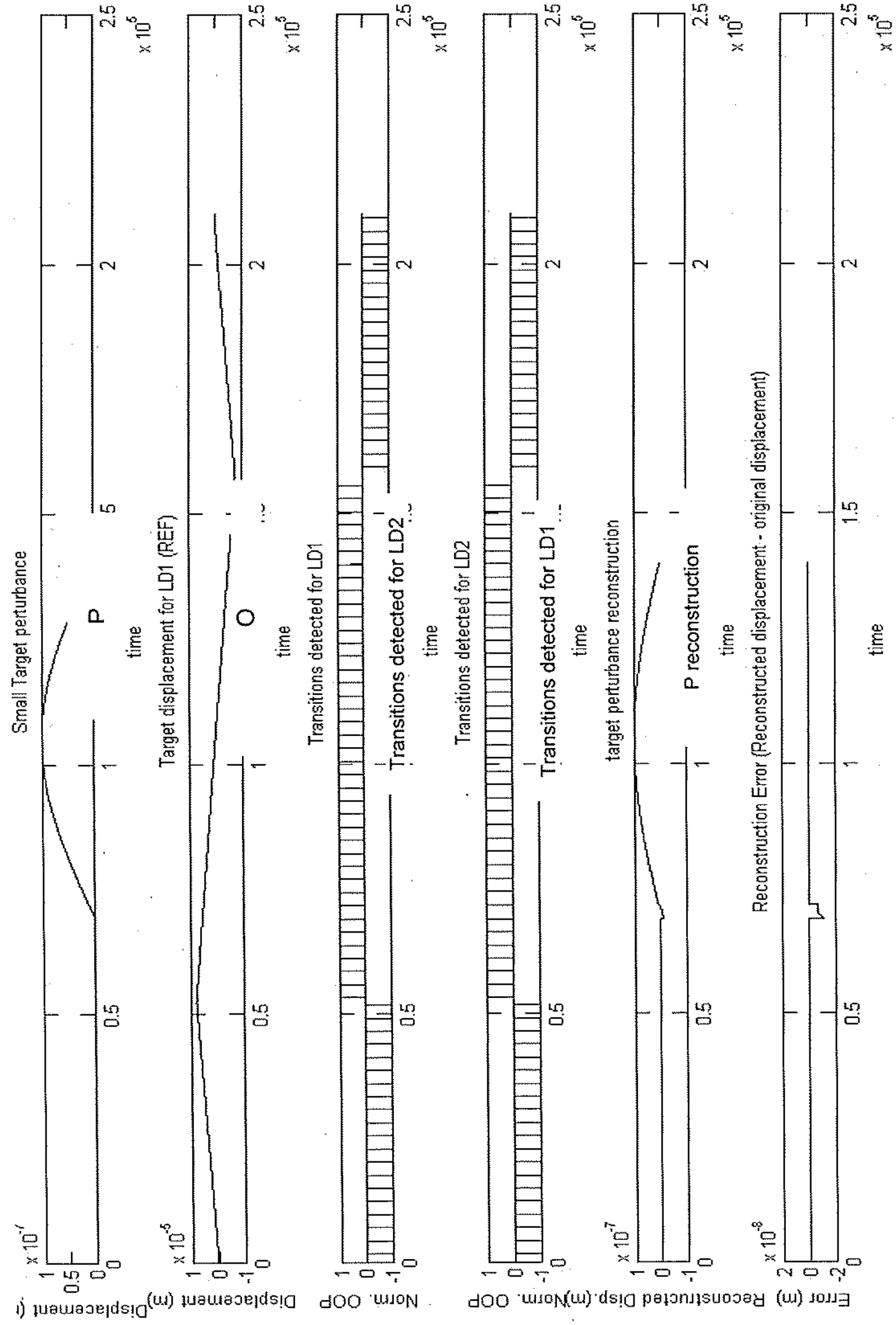
Figure 3



Average Error = 2.23 nm - Maximum Error = 11.2 nm

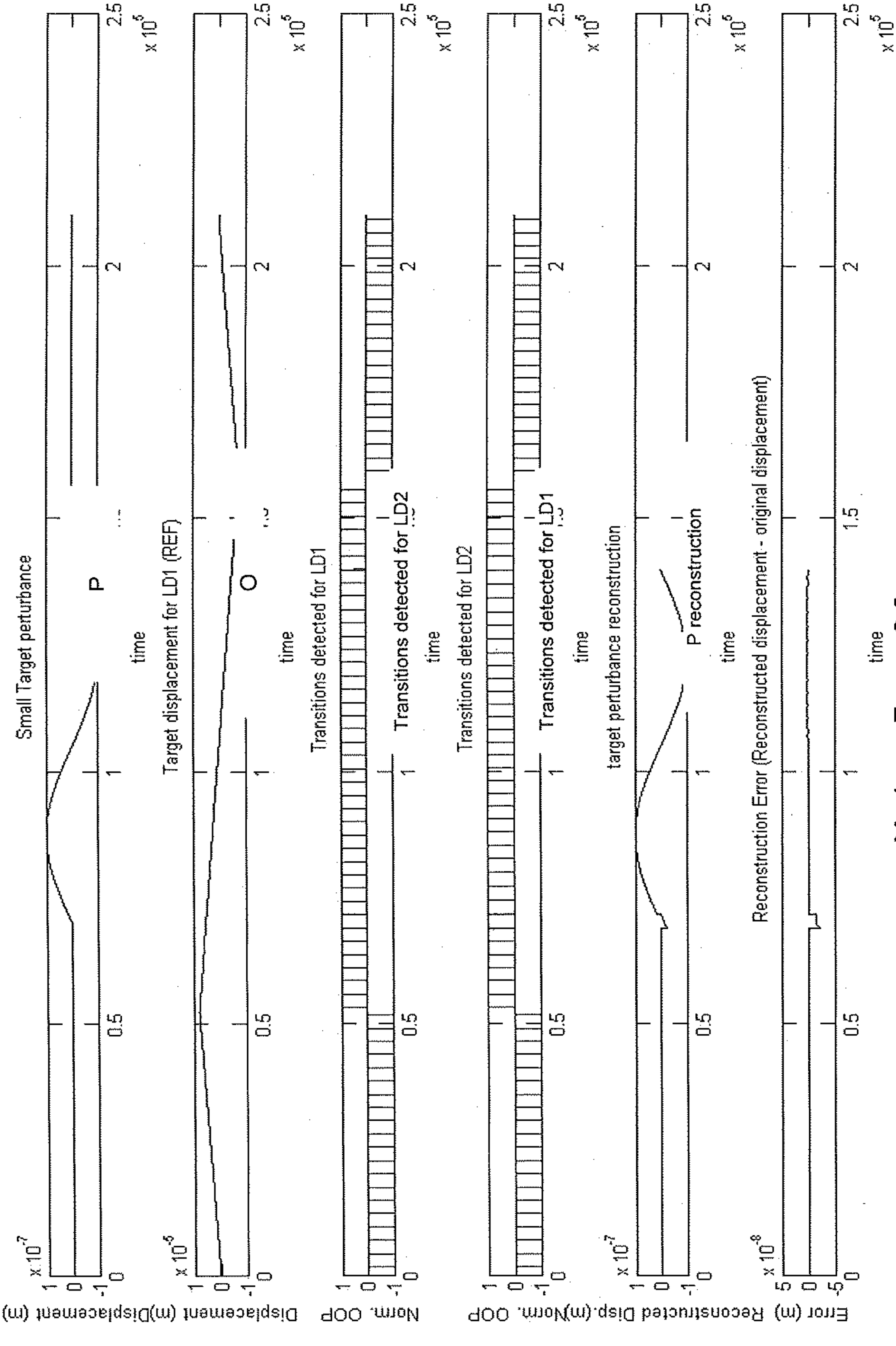
Figura 4


Small Target perturbance
Displacement (m)
x 10^-7
time
x 10^5
Target displacement for LD1 (REF)
Displacement (m)
x 10^-6
Transitions detected for LD1
Norm. OOP
Transitions detected for LD2
target perturbance reconstruction
Reconstructed Disp.(m)
Reconstruction Error (Reconstructed displacement - original displacement)
Error (m)
x 10^-8
Average Error = 3.28 nm - Maximum Error = 10 nm



Maximum Error = 0.001 nm

Figure 5



Maximum Error = 0.6 nm

Figure 6

Figure 7

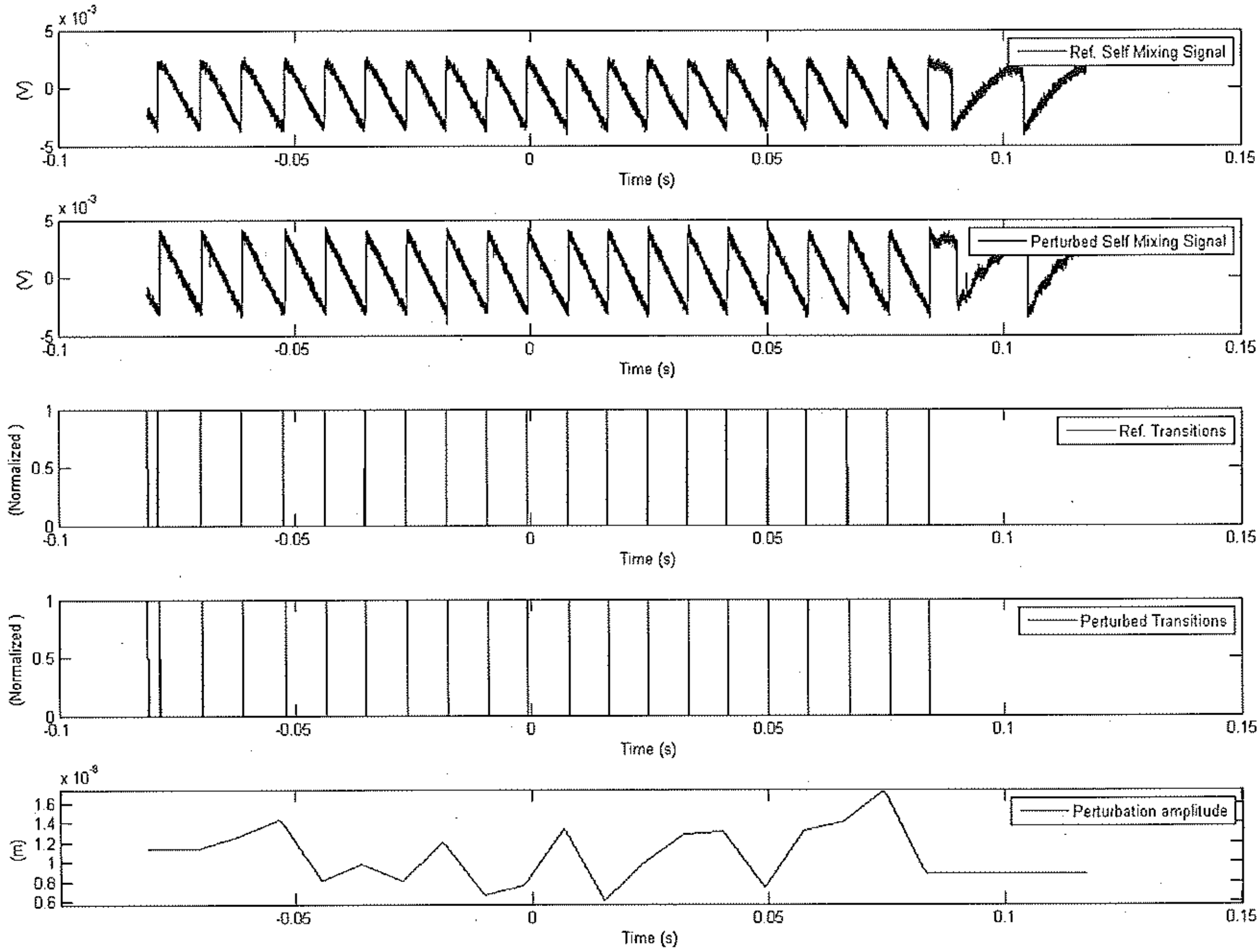

x 10^-3
5
(V)
0
-5
-0.1
-0.05
0
0.05
0.1
0.15
Time (s)
Ref. Self Mixing Signal
Perturbed Self Mixing Signal
(Normalized)
1
0.5
Ref. Transitions
Perturbed Transitions
1.6
1.4
1.2
1
0.8
0.6
(m)
Perturbation amplitude

Figure 8a

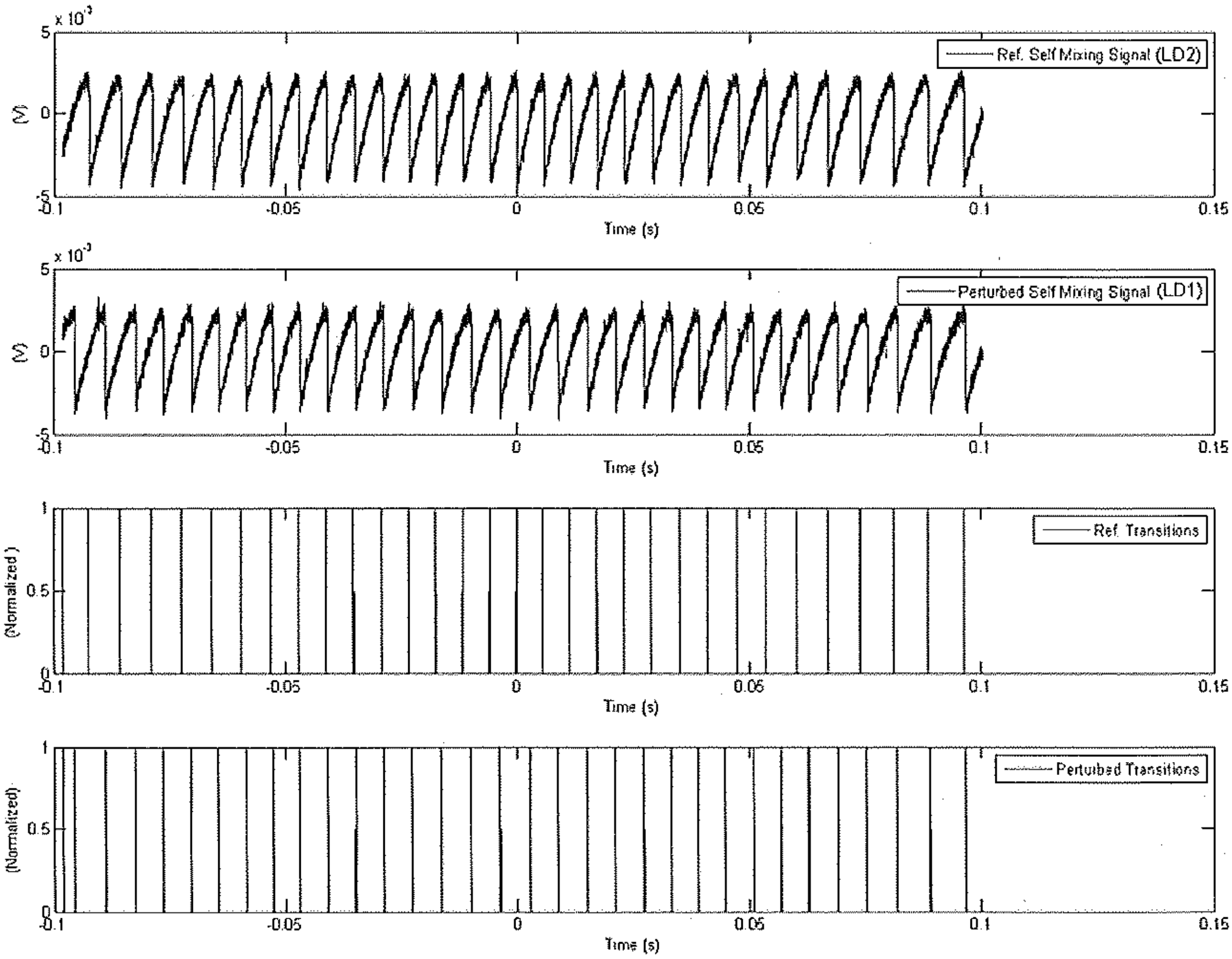

x 10^-3
5
0
-5
(V)
-0.1
-0.05
0
0.05
0.1
0.15
Time (s)
Ref. Self Mixing Signal (LD2)
Perturbed Self Mixing Signal (LD1)
(Normalized)
1
0.5
Ref. Transitions
Perturbed Transitions

Figure 8b

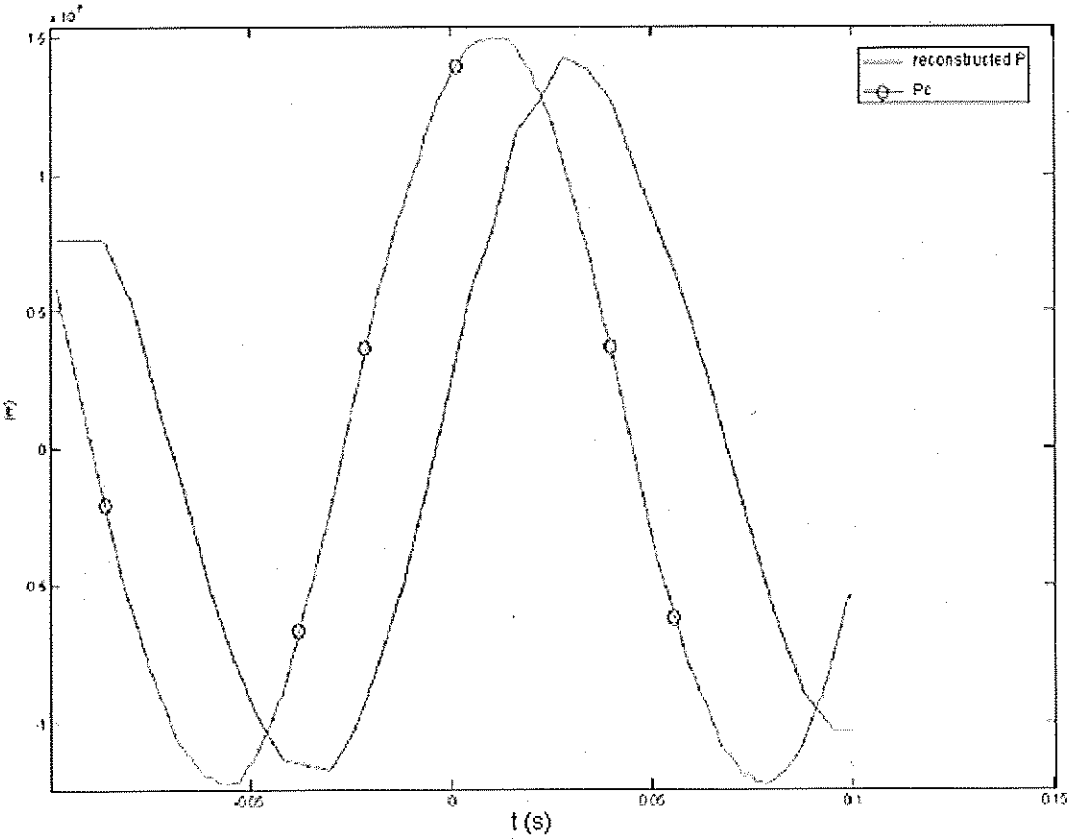


Figure 8c