# 複合型光ファイバによるレーザー治療デバイスの開発

**分担研究者　岡　潔　　独立行政法人　日本原子力研究開発機構　量子ビーム応用研究部門　研究副主幹**

研究要旨
双胎間輸血症候群や胎児脊髄髄膜瘤等の先天性疾患の場合, 出生後の治療には限界があり, 一部の症例では胎児への治療, 特に胎児内視鏡による外科治療が求められていたが, この治療が狭い空間である子宮内（羊水中）に浮遊する胎児を対象とすることから, 現在の内視鏡手術機器には高度な技術的進歩が必要とされてきた. そこで, レーザー照射機能と観察機能を一体化した複合型光ファイバ技術（日本原子力研究開発機構が所有する特許）を医療機器に活用し, 目視観察機能と患部を焼灼するためのレーザー照射機能を小型一体化した, 「レーザー照射機能を有する極細径内視鏡」の開発を目的に, 本年度は, 距離計測及び血流計測機能の追加と性能評価のための動物実験を行い, その有効性を確認した. 並行して, 複合型光ファイバスコープのさらなる細径化を行い, これまでに試作したシステムと組み合わせて動物実験を実施し, その有効性を確認した.

## A．研究目的

双胎間輸血症候群や胎児脊髄髄膜瘤等の先天性疾患の場合, 出生後の治療には限界があり, 一部の症例では胎児への治療, 特に胎児内視鏡による外科治療が求められていたが, この治療が狭い空間である子宮内（羊水中）に浮遊する胎児を対象とすることから, 現在の内視鏡手術機器には高度な技術的進歩が必要とされてきた. そこで本研究では, レーザー照射機能と観察機能を一体化した複合型光ファイバ技術（日本原子力研究開発機構（以下, 原子力機構）が所有する特許）を医療機器に活用し, 目視観察機能と患部を焼灼するためのレーザー照射機能を小型一体化した, 「レーザー照射機能を有する極細径内視鏡」の開発を行うことを目的とする. 本内視鏡を胎内外科治療に適用することによって, 胎盤・胎児治療の高度化を図り, さらに, 母体及び医師の肉体的・精神的負担が軽減できることを期待する.

本年度は昨年度までに試作したレーザー照射機能を有する内視鏡システム(外径φ2mm の複合型光ファイバスコープシステム)を利用し, (1)スコープ先端から対象物までの距離計測方法の検討及び対象物の血流計測方法の検討を実施する. また, (2)外径φ1mm の複合型光ファイバスコープの試作を実施する. 併せて, (3)外径φ2mm の複合型光ファイバスコープシステムを利用した動物実験を実施し, 距離計測及び血流計測方法の有効性を確認することを目的とした.

## B.研究方法

先天性疾患の一つである双胎間輸血症候群を改善するためにレーザー治療が行われているが, 現在の治療器具にはいくつかの問題点がある. ①レーザー照射用光ファイバの走査線と胎児内視鏡の撮影軸が違うため, レーザーの照準が患部にうまく当たらない, ②レーザーから対象物までの距離が明確にわからないため, 患部にレーザーの焦点をうまく合わせることが困難である, ③レーザー照射の量と患部の焼灼量の関係が定量化されていないため, 患部を焼き過ぎる恐れがある, などが挙げられる. これらのことを解決するためには, ①対象物までの位置を把握し, ②血管の血流の有無を確認し, ③患部への正確なレーザー照射を実施するということをシームレスに行う必要がある.

原子力機構では, 溶接・切断用光ファイバ及びレンズ光学系を, 観察光学系としても使用することに着目し, レーザー光と画像を並列伝送可能な光ファイバ(複合型光ファイバ)技術の開発に成功した. 我々はこれまでの経験と技術を活用し, 胎児外科治療で使用されてきた既存の胎児内視鏡の性能を凌駕する「レーザー照射機能を有する内視鏡」を開発するために, 昨年度までに試作した「レーザー照射機能を有する極細径内視鏡(外径φ2mm の複合型光ファイバスコープシステム)」(Fig.1, 2 参照)に適用可能な方法で, (1)複合型光ファイバスコープ先端から対象物までの距離計測方法及び対象物の血流計測方法の検討をそれぞれ実施する. また, これまでよりもさらに細い(2)φ1mm 径の複合型光ファイバスコープの試作を行い, 既存のφ2mm 径との視野角を比較する. 併せて, (3) 外径φ2mm の複合型光ファイバスコープシステムを利用した動物実験を実施し, 距離計測及び血流計測方法の有効性を確認する.
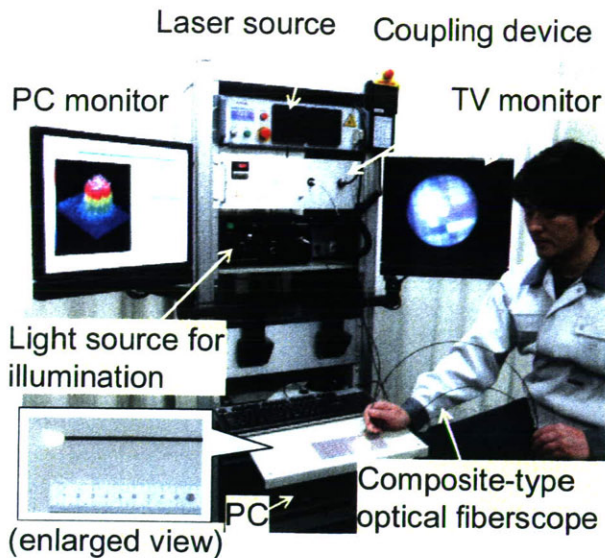
Fig.1 Laser fiberscope for fetal surgical treatment
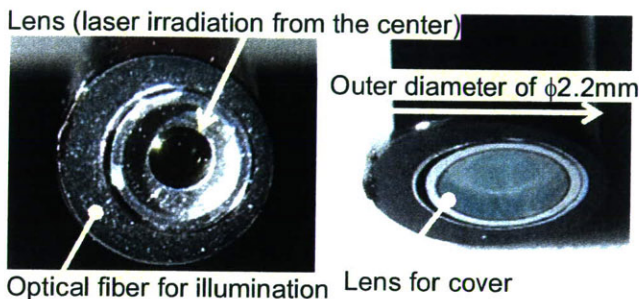


Fig.2 Appearance of the tip of composite-type optical fiberscope

(1)距離計測方法及び血流計測方法の検討

　胎児外科治療の１つである胎児鏡下胎盤吻合血管レーザー焼灼術においては，胎児鏡の視認性(単眼)の問題から，レーザー照射器である光ファイバとその先にある胎盤あるいは胎児との間の距離が把握しにくく，術者の不注意により手術器具が胎盤及び胎児に接触してしまうことがある．従って，手術の成功を高めることと医療事故を防ぐという観点からも，視界不良の羊水中において，手術器具と対象物との距離を常に把握しておくことは大変重要である．また，レーザー焼灼前に血管中における血液の流れを把握し，血管焼灼後には目視による血管凝固の確認のみではなく，血流が確実に遮断されたかどうかを定量的に計測することも大変重要である．

　そこで，本複合型光ファイバスコープ(以下，スコープ)が光ファイバの束により構成されている点に着目し，その特徴を活かして距離測定機能及び血流計測機能を搭載することを検討する．具体的には，対象となる血管に対して，焼灼用レーザーとは別の波長の微弱なレーザー光を照射し，その反射光を利用した距離計測方法及び血流計測方法を検討するもので，市販の血流計測装置の組み込みを前提とし

て本スコープが血流計測装置と統合して使用可能かどうか検討する．

(2)外径φ1mm の複合型光ファイバスコープの試作

　先端部に石英レンズを搭載し，最大出力 50W のエネルギーを持つ Yb ファイバレーザー光(波長：1075nm 近傍)を導光可能であり，かつ，対象物からの実画像を併行して伝送することが可能で外径φ1mm を目標とした複合型光ファイバスコープを試作する．設計仕様を Table 1 に示す．試作後，既存のφ2.2mm 径と新規試作するφ1mm 径で視野角の比較を行い，実際の使用に耐えうるかどうかの評価を行う．

Table 1　φ1mm 複合型光ファイバスコープの設計仕様(目標)

| 項　目 | 設計仕様 |
|---|---|
| スコープ全体外径 | 1mm |
| レーザー伝送部　コア径 | $100\pm15\mu m$ |
| レーザー伝送部　クラッド径 | $120\pm20\mu m$ |
| 画像伝送部　画像伝送部径 | $465\pm15\ \mu m$ |
| 画像伝送部　光ファイバ外径 | $500\pm20\ \mu m$ |
| 画像伝送部　コーティング径 | $600\pm30\ \mu m$ |
| コア材質 | Ge ドープ石英ガラス |
| クラッド材質 | 純粋石英ガラス |
| N.A | 0.2 |
| 画像伝送用画素数 | 約 9,000 画素 |
| 対物レンズの材質 | 石英ガラス (屈折率：1.45) |
| 対物レンズの　視野角度 | 約 50～60° |
| 対物レンズの　焦点距離 | 約 10mm |
| 対物レンズの　焦点深度 | 3～50mm |

(3)動物実験

　外径φ2.2mm の複合型光ファイバスコープシステムを利用した動物実験を実施し，距離計測及び血流計測が可能かどうか，本システムの妥当性の検証を行うと共にその有効性を明らかにする．

(倫理面への配慮)　動物モデル（豚）を使用した実験では、国立成育医療センター動物管理委員会の定める規定に厳密に則って行なった．

## C.研究結果

### (1)距離計測方法及び血流計測方法の検討

距離測定機能及び血流計測機能を本システムに組み込むため，市販されている装置のうち，①計測用レーザーが光ファイバにて伝送されるタイプの血流計である，②非接触で血流計測可能である，③レーザー出力に対する対象物からの反射光量を計測可能である，④計測器から外部へデータ出力可能である，という観点から，Fig.3 に示すような株式会社アドバンス製 ALF21N を使用することにした．



Fig.3 Blood flow meter

本装置は半導体レーザー光を用いた非観血式のレーザー微小循環血流計で，本体及び測定部位へレーザー光を導く専用プローブで構成されている．本装置前面には専用プローブを接続するレーザー発光部及び受光部があり，接続した専用プローブから出たレーザーが生体に反射し，その反射光をプローブで受光して本体にて信号処理を行うことで血流情報が得られる．取得した血流情報は前面に表示し，血流情報に相当する電圧値を背面のポートから出力する機能を有している．本装置では，組織血流量(FLOW)，組織血液量(MASS)，血流速度(VELOCITY)，全受光量(REFLEX)が取得可能である．また，得られた値を電圧値へと変換して背面のポートから出力する機能も有している．この電圧値は受光した反射光をフォトセンサで変換しアンプで増幅したものである．なお，REFLEX 値はプローブ先端と測定する患部の間の距離に応じて変化するため，測定時の距離の目安として装置前面に LED ゲージとして設置されている．本研究では，この REFLEX 値のアナログ電圧値を PC に取り込み，対象物までの距離として換算利用した．ここで，本装置は，①水中下で使用する，②複合型光ファイバスコープに組み込む，③非接触で遠距離から血流測定する，という観点から，(a)内部に搭載したレーザー源の出力向上，(b)レーザー反射光の受光感度を調整可能とする機構の搭載，(c)焼灼・計測用レーザー光及び画像を統合・分離する機能を有するカップリング装置への改造，をそれぞれ実施して，既存システムに血流計測装置を接続可能とした．なお，外径が小さなスコープは，血流計測用のレーザー光を導光する光ファイバの数が必然的に減少し，レーザー光量が減少するため，既存のφ2.2mm 径と新規試作するφ1mm 径のスコープではそれぞれの光量に合致する内部調整を施した血流計を使用することとした．

Fig.4 は血流計を接続可能に改造したカップリング装置である．本装置は Yb レーザー光を入射し，1075nm の波長のみを反射する誘電体多層膜ミラーにより，複合型光ファイバスコープにレーザー光を集光する．一方，血流計測用のレーザー光(波長：780nm)は，照明光の伝送に使用している光ファイバの一部を使用して直接入射・導光し，スコープ先端から対象物へレーザー光を照射した．対象物の血流
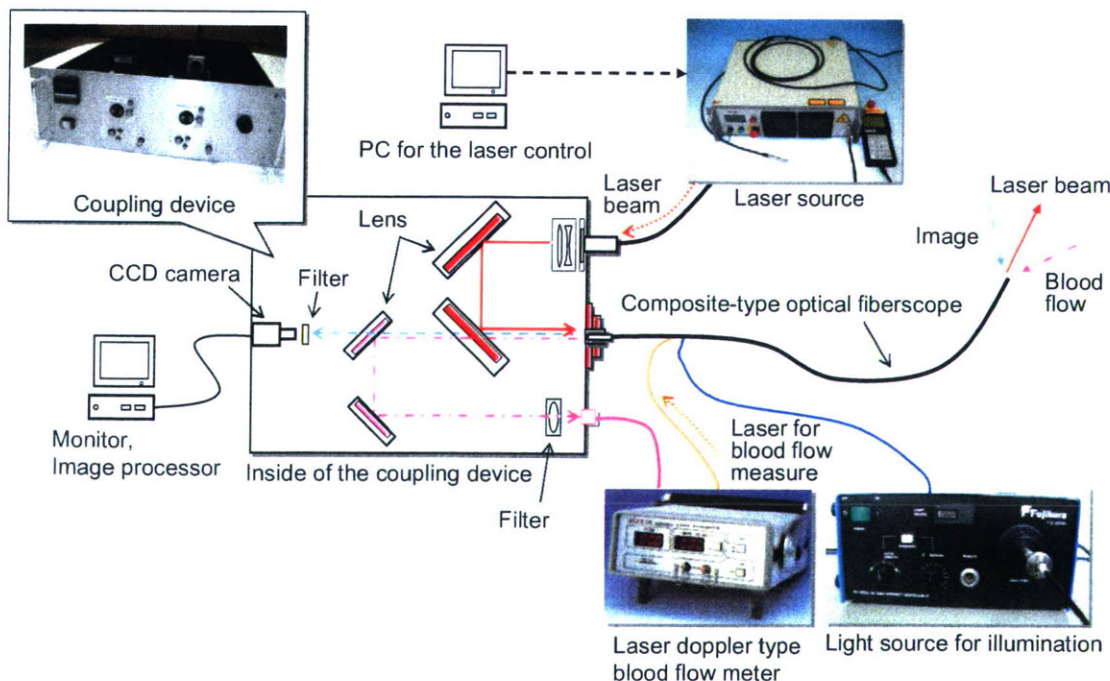


Fig.4 Composite-type optical fiberscope system combined with a blood flow meter

計測を行うために，対象物からのレーザー反射光(散乱光)をスコープの画像伝送用光ファイバを使用して導光し，カップリング装置内で血流計測用に使用している 780nm の波長のみを取り出すことが可能な誘電体多層膜ミラー及びフィルタを利用して血流計に導光可能とした．

Fig.5 は，本システムに血流計測装置を組み込み，水中にて豚の腸間膜血管(in vivo)と φ2.2mm 径の複合型光ファイバスコープ間の距離を変化させた場合の電圧値の応答を示す．横軸が規定の距離，縦軸が血流計から得られる反射光量(REFLEX 値)から推測した距離を示している．実験では，豚の腸間膜血管とスコープ間の距離を 5mm に設置し，この距離を初期位置として距離 20mm まで 1mm ずつ離して反射光量を計測した．各距離で電圧値を 10 秒間取得し平均化している．実験で得られたデータを基に，距離と電圧値の関係式を推定した. 図中の赤丸(測定値)と推定した近似式(黒線)を比較した結果，ほぼ±1mm 程度の誤差であった．これによって，精度 1mm 程度で対象物までの距離を測定可能とした．
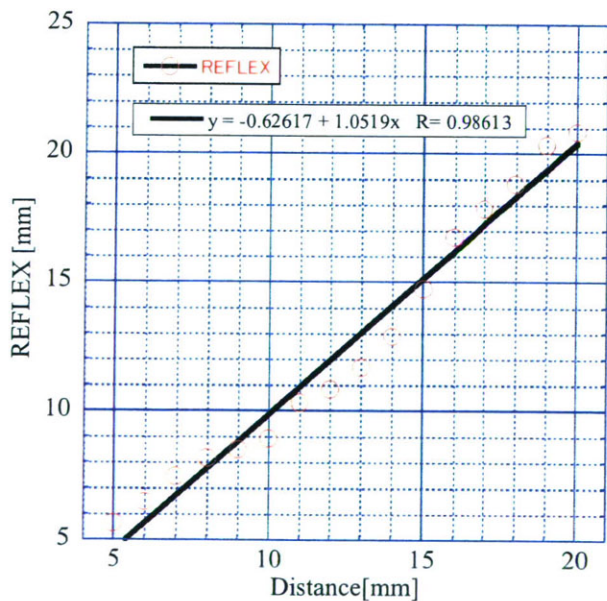
※血流計測の結果に関しては，後述する.



Fig.5 Result of the distance test with mesenteric vein (in vivo)

(2)外径 φ1mm の複合型光ファイバスコープの試作

先端部に石英レンズを搭載し，最大出力 50W のエネルギーを持つ Yb ファイバレーザー光(波長：1075nm 近傍)を導光可能であり，かつ，対象物からの実画像を併行して伝送することが可能で外径 φ1mm を目標とした複合型光ファイバスコープを試作した．試作した φ1mm 径と φ2.2mm 径の複合型光ファイバスコープ外観の比較を Fig.6 に示す．また，試作後に計測した仕様(実測値)を Table 2 に示す.
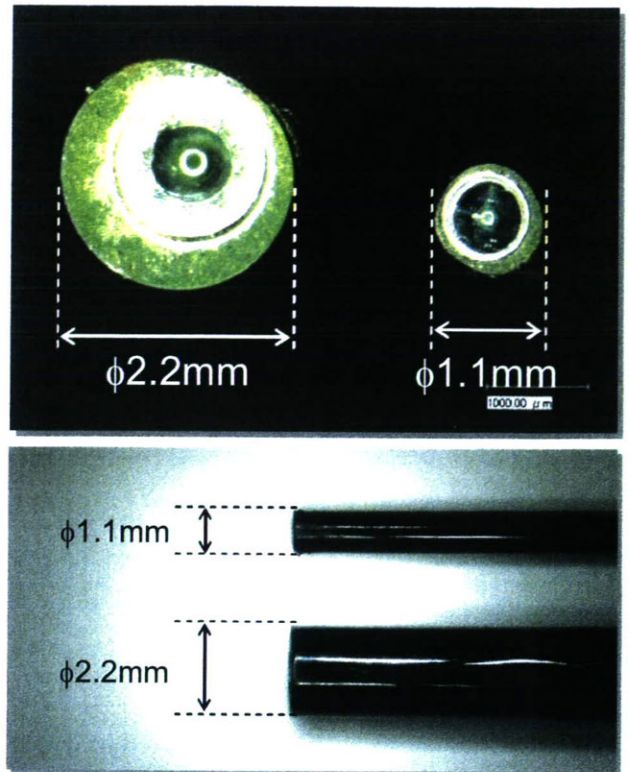


Fig.6 Prototype of φ1.1mm composite-type optical fiberscope

Table 2 試作した φ1mm 径の複合型光ファイバスコープの実測結果

| 項　目 | 実測結果 |
|---|---|
| スコープ全体外径 | φ1.1mm |
| レーザー伝送部 コア径 | 108μm |
| レーザー伝送部 クラッド径 | 129μm |
| 画像伝送部 画像伝送部径 | 453 μm |
| 画像伝送部 光ファイバ外径 | 487 μm |
| 画像伝送部 コーティング径 | 573 μm |
| コア材質 | Ge ドープ石英ガラス |
| クラッド材質 | 純粋石英ガラス |
| N.A | 0.2 |
| 画像伝送用画素数 | 9,498 画素(計算値) |
| 対物レンズの材質 | 石英ガラス (屈折率：1.45) |
| 対物レンズの 視野角度 | 約 50〜60° |
| 対物レンズの 焦点距離 | 約 10mm |
| 対物レンズの 焦点深度 | 3〜50mm |

水中下での画像観察の結果を Fig.7 に示す. 観察対象は 1 辺が 1mm 角のカラーチャートである. 外径φ1.1mm のスコープのレーザー導光部分が大きくなり, 視野が狭くなっているように見える. また, 画角が狭く, 映像も暗くなっていることがわかる.
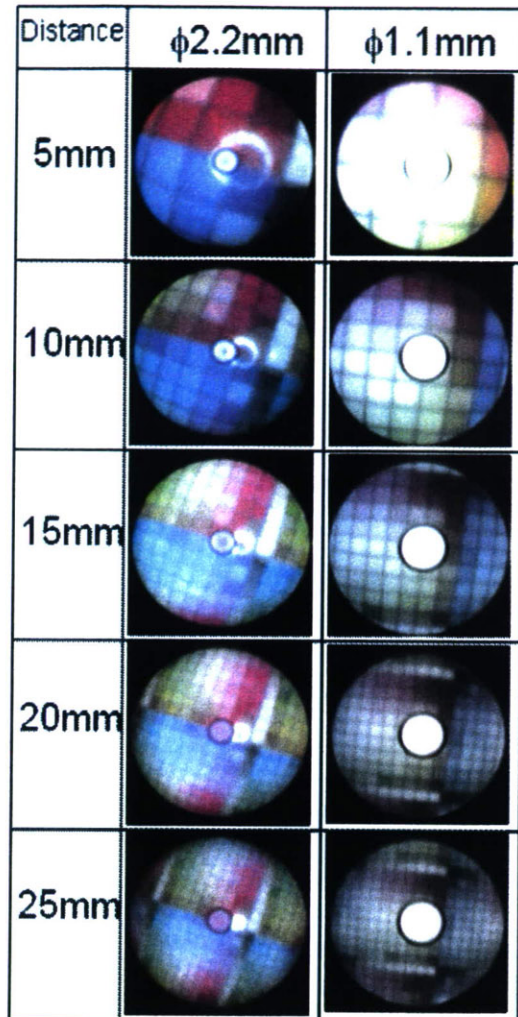


Fig.7 Angle of view of fiberscope

次に, 実際に豚の腸間膜血管を観察した結果(距離：10mm)を Fig.7 に示す. カラーチャートを観察した場合と同様に視野の狭さと映像の暗さがわかる.
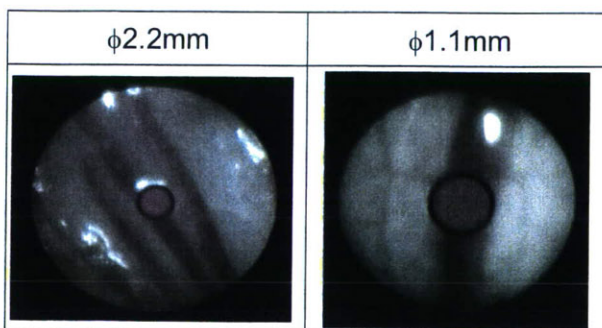


Fig.8 Observation result of the mesenteric vein (in vivo)

しかしながら, 先端レンズ径の縮小及び照明用ファイバの数量減少など, 現状では打開できない問題点であり, 本試作品単体の性能としてはほぼ妥当であろう.

**(3)動物実験**

外径φ2.2mm の複合型光ファイバスコープシステムに血流計測装置を組み込み, in vivo にて豚の腸間膜血管に対してレーザー照射試験を行った. 本試験では, PC からのトリガ信号を, DA 変換器を介してレーザー装置へ入力することで, 照射時間の正確な設定を可能にした. また, 別途, 本システムとは独立した市販の血流計測装置を使用し, 本システムに接続した血流計測装置との比較を行なった.

試験条件として, 外径φ2.2mm のスコープにて, 水中下, 太さ約 0.5mm の腸間膜血管に対し, 照射距離 10mm, レーザー出力 30W, 照射時間 3 秒で照射試験を実施した. その結果, すべてのレーザー焼灼試験において, その様子を観察することができた. Fig.9 にレーザー焼灼した結果の一例を示す.



Fig.9 Laser cauterization result

Fig.10 に血流計測結果の一例を示す. グラフは横軸が時間, 左縦軸は FLOW, VELOCITY を表しており, 右縦軸は MASS を表している.



Fig.10 Test result of the blood flow measurement

このように, レーザー焼灼前後の血流値をリアルタイムに計測することができた. グラフからわかる

ように，レーザー焼灼後の FLOW(血流量)及び VELOCITY(血流速)は減少するが，MASS(血液量)は増加することが明らかとなった．これは通常の血流計測装置で計測した結果と類似の傾向を示している．また，レーザー焼灼中はその反射光により，血流計測値に若干の乱れがみられるが，今後，波長フィルタを追加することで改善可能であると考えられる．
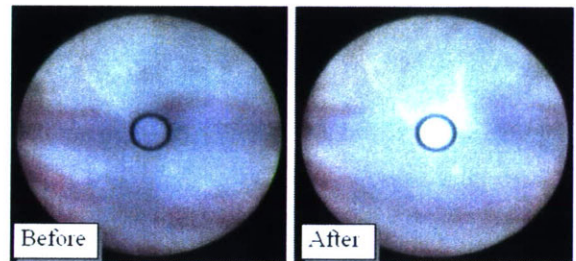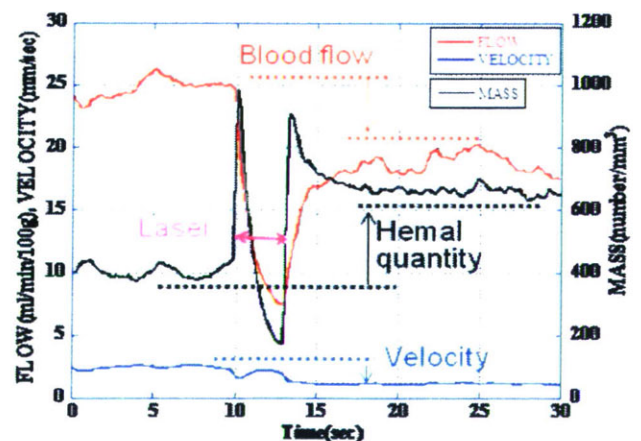
## D.考察

対象物に別の波長の光を照射することで，距離情報及び血管の血流状態を取得可能であると推察され，既存のカップリング装置と市販の血流計測装置の改造及び組み合わせを検討した．

本システムを使用して，豚を用いた総合的な動物実験(in vivo)を行った結果，1 本の複合型光ファイバスコープを使用するだけで，(1)観察，(2)距離計測，(3)レーザー焼灼，(4)血流計測，をシームレスに行えることを実証した．

本機能を使用すれば，視界の悪い胎内において，レーザー照射器とその先にある胎盤あるいは胎児との間の距離を把握することができ，術者の不注意により手術器具が胎盤及び胎児に接触してしまうことを軽減できると考えられる．また，レーザー焼灼前に血管中における血液の流れを把握し，血管焼灼後には目視による血管凝固の確認のみではなく，血流が確実に遮断されたかどうかを定量的に計測することも可能となる．

並行して，外径φ1.1mm の複合型光ファイバスコープの試作に成功し，その有効性を明らかにした．これによって，例えば，Richard WOLF 社など通常の臨床現場で使用されている既存の胎児鏡との併用も可能であると考えられ，ニーズに応じて，より安全・安心な手術への期待が持てる．

今後も，本システムの更なる改良と動物実験等を行うことで，臨床応用へ向けた製品の開発研究を推進できると考える．

## E.結論

今年度は外径φ2.2mm のレーザー照射機能と観察機能が一体化した複合型光ファイバスコープシステムに距離計測機能及び血流計測機能を追加した．さらに，外径φ1.1mm の複合型光ファイバスコープの試作に成功した．また，これらを使用して動物実験を行い，その有効性と優位性を明らかにすると共に，今後のシステムの発展性を見出せた．

## F.健康危険情報

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## G.研究発表

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## H. 知的財産権の出願・登録状況

### 1. 特許取得
なし

### 2. 実用新案登録
なし

### 3. その他
なし

別紙4

<div align="center">研究成果の刊行に関する一覧表レイアウト</div>

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# Balloon-Based Manipulator with Multiple Linkages for Intrauterine Surgery

Noriaki Yamanaka, Kiyoshi Matsumiya, Ken Masamune, Takeyoshi Dohi
*Graduate School of Information Science and Technology, The University of Tokyo*

Hiromasa Yamashita, Toshio Chiba
*Department of Strategic Medicine, National Center for Child Health and Development*

Hongen Liao
*Graduate School of Engineering, The University of Tokyo*

*Abstract* — This paper describes a manipulator for controlling position and posture of fetus in uterus and a surgical procedure for supporting the fetus in intrauterine surgery. The manipulator is equipped with multiple linkages and a balloon to support the fetus softly in the uterus. The linkages with two bending mechanisms are designed for inserting the balloon to an optimal position under the fetus. The balloon is fold before the operation and inflated by saline water after arriving at the required position in the uterus. Accuracy evaluation showed that the standard deviations of the bending angle of the wire-driven mechanism and the linkages-driven mechanism were 1.0 degree and 2.5 degree, respectively. Force experiment showed that the balloon-type stabilizer could generate load-bearing power of 500 gf. Furthermore, the manipulator could be well controlled with guidance of ultrasound images. The manipulator could minimize injure to the fetus since the area contacted with the fetus by the balloon could be well controlled.

## I. INTRODUCTION

MYELOMENINGOCELE (MMC) is one of the most common in spina bifida, which is a devastating congenital defect of the central neural system. The patient suffers from orthopedic disabilities, bowel and bladder dysfunctions and mental retardation after birth. This disease occurs 1 case per 2000 birth, and the rate tends to increase.

The disease of MMC is that when neural cord is constructed in early gestation, this process is not completely done and the tube is left opened. Additionally vertebral arches and skin on it are also not closed. Although these primary defects occur, the neural tissue itself is normal in early gestation. Since the spinal cord is exposed in uterus, direct trauma, hydrodynamic pressure and chemical stimulus by amniotic fluid damage spinal cord in whole period of gestation, which causes secondary injuries. And leak of cerebrospinal fluid (CSF) through the opened spinal cord may cause Arnold-Chiari malformation (hindbrain hernia) leading to hydrocephalus.

The treatment for MMC after birth aims to prevent spinal tissues from infections by neurosurgical approach, but it is not an effective method. To prevent dysfunctions, the treatment should be performed before the destruction of the spinal tissue since the functions becomes irreversible after the birth. Surgical treatments like covering, suture and patch the spinal cord in fetal surgery, could prevent it from secondary damages and maintain the neural functions [2,3]. Fetal neural tissue may regenerate if an injury occurs prior to myelination which almost completes at 24 weeks gestation. The damage on the spinal cord will be small when the earlier repair is performed. However, the treatment before 18 weeks gestation is technically difficult because the skin of the fetus is fragile like gelatin. Most of the treatments on fetus are performed from 19 to 24 weeks gestation [1].

Up to now, fetal treatment for MMC is open surgery. Endoscopic approach is preferable [6-12], since it is minimally invasive to the mother and the fetus and could decrease the risk of complications, for example prematurely delivery [3-5]. However, endoscopic surgery is difficult to be performed since it requires more skill. Another reason is that since the fetus is floating in amniotic fluid, it is difficult to perform a long and precision treatment. To solve these issues, a device is required to stabilize the fetus in endoscopic intrauterine surgery [9-12].

Previous study includes development of a suction type stabilizer with silicone tube is small for insertion to uterus [10]. However, the area of the fetal skin sucked by negative pressure may be congested with blood. We developed a manipulator with flexible balloon-based stabilizer [11]. The area to contact with the fetus becomes large by swelling a balloon after insertion to the uterus. However, the umbilical cord may be pressed when the fetus is supported beneath because balloon is inflated into a circular shape.

We develop a new manipulator which can avoid the umbilical cord. The manipulator can be separated for sterilization and the balloon can be used to stabilize the fetus in a large area. The results of mechanical performance, balloon load-bearing power and fetal model supporting under the ultrasonic images guidance are also described.

## II. Methods and Materials

We designed and fabricated a prototype of manipulator to support fetus in uterus. The diameter of incision should be small for minimally invasive surgery. Manipulator has holding mechanism which consists of two bending mechanisms, one is used to bend hook-like mechanism with a balloon to a required shape in fetus supporting, and another is used to adjust the holding plane of the hook-like mechanism. Ultrasound and endoscope are also used to guide the intrauterine surgical treatment.

### A. Procedure to support fetus

Fetus is rotated and moved when being pushed at lumbosacral area during surgery. The center of mass is around chest. In order to support fetus stably without touching umbilical cord, trunk of the body especially from side to chest should be held up below abdomen (Fig.1). Supporting stability is ensured by making contact area large in orientation of fetal height and fit the fetal waist. It is easy to keep away from the umbilical cord by large space around umbilicus.

The manipulator is equipped with two bending mechanisms. One is for getting the hook-like mechanism with a silicone balloon into a required shape in fetus supporting and the other is for adjusting the plane of the hook-like mechanism corresponding to insertion angle and point which is far away from place of placenta.

The procedure of the manipulator is supposed as follows. To ensure the surgical space of intrauterine treatment, the uterus can be inflated with saline or Ringer's solution. The manipulator is arranged as straight form and the balloon is fold to be minimum size before the insertion. Then the manipulator is inserted through a trocar fixed on a small incision in the back side of the fetus. The holding mechanism is bent to suit the fetal body and the balloon is swollen up with saline under the guidance of endoscope and ultrasound.

### B. System configuration

System of the manipulator is configured with manipulator itself, control unit and water injection unit (Fig.1). We control the manipulator by a dialog on PC. Water injection unit includes tubes made of teflon and silicone and a roller pomp to keep saline clean easily.

Ultrasound and fetoscope is necessary to observe in uterus. Since the sight of fetoscope is narrow and may be cloud by amniotic fluid, ultrasound plays major role.

### C. Manipulator mechanism

Holding mechanism is the most important part of the manipulator to support fetus in uterus.

Hook-like mechanism for supporting fetus consists of 5 frames connected by pin, which means 4 joints, and driven by two stainless steel wires (Fig.2). The wires, tied to the tip frame, pass through each side of the other frames and tied to a pulley with different radius for reeling up and reeling off.
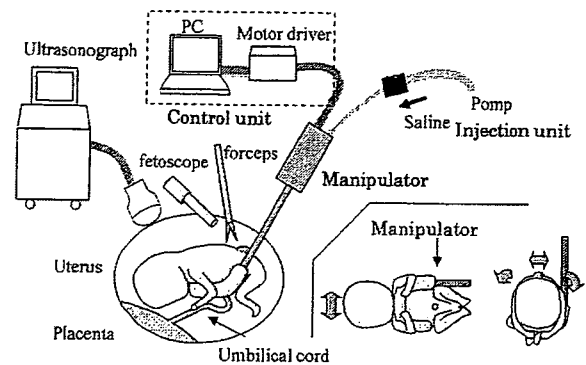


Fig. 1. System configuration and method of supporting fetus. Manipulator fits the fetal abdominal sides from the beneath.
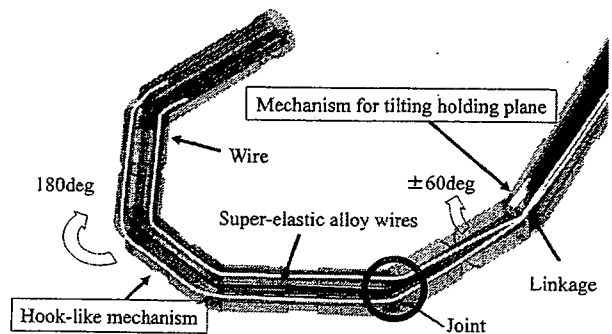


Fig. 2. Holding mechanism. Hook-like mechanism is driven by wires. Bending space is small since manipulator bend from tip by super-elastic alloy wires. Mechanism for tilting holding plane is controlled by the linkage corresponding to the insertion point.

Since each of 4 joints can bend 45 degree, manipulator can bend 180 degree as a whole. By bending, the width between tip and root frame gets smaller and meet the fetal abdominal sides, and the middle frame supports the chest. The size of the fetus would be various because the period for surgery is long and the development of the fetus would be different one by one. In order to meet wide range of the size, the bending angle can be fine controlled.

The hook-like mechanism should be bent into a half circle of about 180 degree for corresponding small fetus, while the angle should be smaller if the fetus is bigger. Further, it is taken into consideration that the space made by bending should be small in order to reduce the risk of contact with placenta. It depends on the sequence of bending, as it is smallest in bending from tip or the largest in bending from root side. The hook-like mechanism bends from tip in sequence since the joints have different hardness in order by super-elastic alloy wires, of which diameters are 0.3 mm and 0.5 mm. The wire tension becomes larger with bending point coming to root frame.

The other mechanism on base shaft bends vertical to holding plane, corresponding to insertion angle and point (Fig.2). The range of bending is ±60 degree. This mechanism is driven by linkages, so as to withstand heavy moment while supporting fetus. And the motion driven by linkage without slack and elongation is more accurate than that driven by

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wire.

In practical use, surgical tools have to be cleaned and sterilized. The holding unit meets autoclave sterilization and can be separate from driving power unit, which meets ethylene oxide gas (EOG) sterilization for electric devices. The pulley for wires is connected to motor at an Oldham's coupling, and driven directly by motor (RE10, maxon). An attachment on the linkage rod fits a nut on feed screw, which is connected to a motor for converting rotation to linear movement, and a taper key locks them (Fig.3).

The manipulator weighs just 450 g as a whole, due to the smallness and lightness of the motor. It is not hard to operate during surgery.

### D. Balloon mechanism

Balloon is made of silicone because rubber expands to larger size and absorbs shock softly than plastic sheet, and latex may cause allergy. The balloon, of which membrane is about 0.3 mm thick, consists of two cylinder bonded on outside. One cylinder is for expanding to support fetus, with a slender silicone tube to connect to stainless tube in the pipe of holding unit. The other cylinder is for covering the mechanisms.

As well as the holding unit and driving power unit can be sterilized, the balloon is to be disposable and can be separated from the holding unit. When the balloon is attached to the holding mechanism of the manipulator, hook-like mechanism is inserted to covering part of the balloon and the silicone tube connect to stainless tube, then balloon is fixed on gap of each frame by clips (Fig.4). Since the balloon follows the holding mechanism, balloon can turn to appropriate shape by its bending (Fig.5).

Sterilized air is an option for balloon inflating. However, it has a risk of leak, furthermore, reflection of the air will limit the use of ultrasound device. Since saline also assures safety and ultrasound can pass through it and we can observe under balloon. In this study, the balloon is inflated with saline.
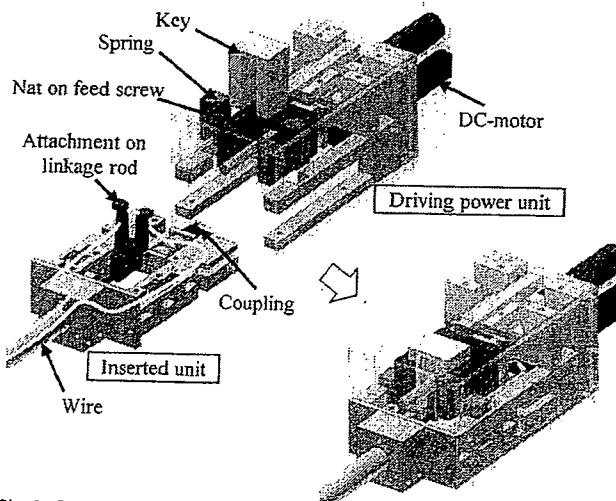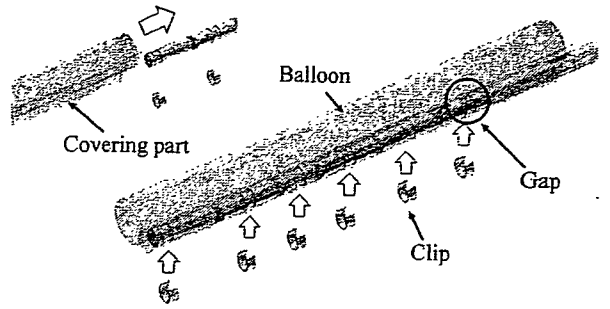

Fig. 4. Manipulator equipped with balloon. Manipulator is inserted into covering part on balloon and fixed by clips.
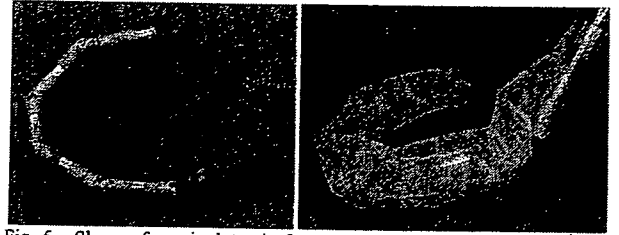

Fig. 5. Shape of manipulator in fetus supporting. Left: without balloon. Right: with balloon inflated by air.

### III. EXPERIMENTS AND RESULTS

We carried out quantitatively evaluation for accuracy of bending performance and load-bearing power of the inflated balloon, furthermore qualitatively estimation of supporting a fetus model in water close to a practical situation with ultrasound guidance.

### A. Accuracy evaluation of bending performance

The hook-like bending mechanism is most important part to support the fetus with fitting fetal abdominal sides. We examined the accuracy of the bending angle from 0 degree to 180 degree in steps of 30 degree with 5 trials. We took photos of the mechanism by a digital camera (Lumix DMC-FZ5, Panasonic) and calculated the bending angle between tip frame and root frame on photos (Fig.6). Since it bent about only half angle against input in former test, we gave double theoretical pulse number from PC.

Although the result showed that the error between theoretical and experimental performance was very big, the manipulator could bend from 0 degree to 176.9 degree and the standard deviation was within almost 1.0 degree, excepting one point around 0 degree, of which standard deviation was 5.2 degree (Fig.7-Left).


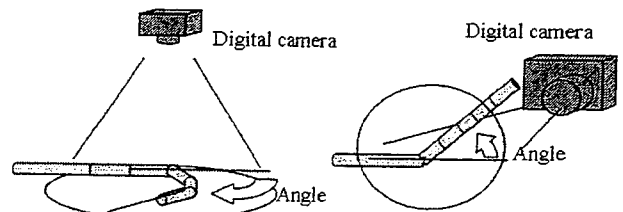Fig. 3. Inserted unit and driving power unit are separated.


Fig. 6. Experiment setup of bending performances evaluation. Left: for holding fetus. Right: for adjusting holding plane.
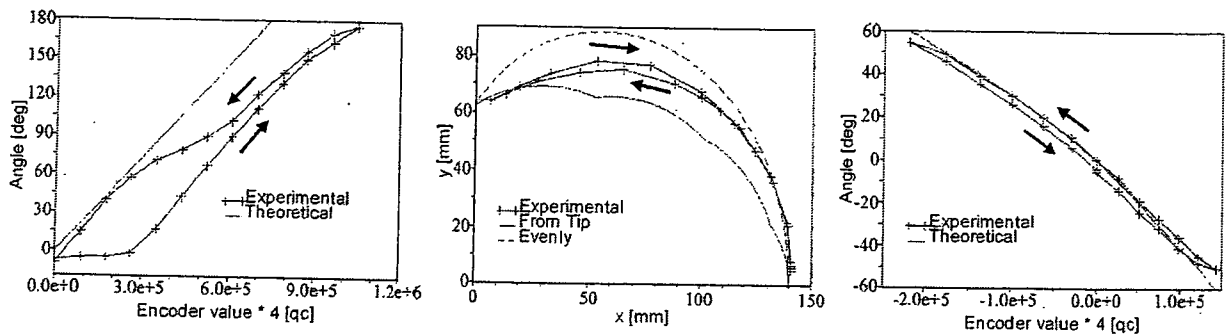
Fig. 7. Result of bending performances evaluation. Left: driven by wire for holding fetus. Center: path of end-effector. Right: driven by linkages for adjusting holding plane.

The path of the end-effector was also evaluated. The experimental space is larger than the theoretical one in bending from tip, but smaller than the theoretical one when all joints bend evenly (Fig.7-Center).

The bending mechanism for insertion angle consists of linkages. We carried out a test for evaluating accuracy of bending angle from -60 degree to 60 degree in increments of 10 degree. And we measured the bending angle between base shaft and root frame of hook-like mechanism.

The experiment showed that manipulator bent from -50.4 degree to 54.6 degree against target angle from -60 degree to 60 degree, and that standard deviation was 2.5 degree (Fig.7-Right).

### B. Feasibility evaluation of balloon-type fetus supporting

We measured load-bearing power and softness of the inflated balloon to evaluate the safety in supporting fetus. Load-bearing power of the balloon means maximum force the balloon generates without contact fetus and the frames of the manipulator in supporting the fetus. We put the holding mechanism with the balloon in water and bent hook-like mechanism about 180 degree and injected water by pomp. After injecting water for over 60 second, we measured the power 5 second apart until the balloon was broken. We pushed down the balloon vertically with a case to contact whole balloon, measuring the whole load-bearing power by digital force gage (Fig.8). The case was a little heavier than water and the contact area is 90 mm × 60 mm. Furthermore, we measured partly load-bearing power to estimate the softness of balloon. We measured the power of the balloon on three points; the tip, the middle and the root frame of the hook-like mechanism with a cylinder of diameter 20 mm. We made the average value of the three as a partly load-bearing power. We carried out the experiment for two balloons.

The experimental results showed that whole load-bearing power of one balloon was up to 520 gf and the other was up to 620 gf. In addition, the partly load-bearing powers of both balloons were about 100 gf when the balloons generated 500 gf as a whole load-bearing power.
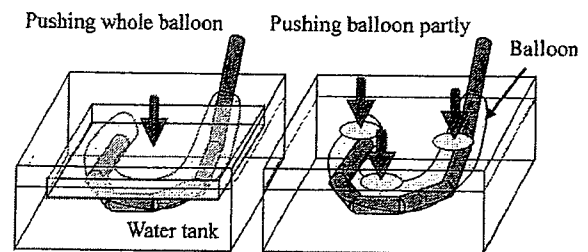


Fig. 8. Pushed area of balloon. Left: pushing whole balloon with case. Right: pushing three points; tip, middle and root frame.

### C. Simulation experiment of fetus model supporting

We estimated the size, the bent shape of manipulator and the procedure in fetus supporting.

1) Fetus model is placed in water simulated as amniotic fluid. The fetus model weighed 690 g, its volume is about 700 $cm^3$, its height is about 35 cm and width of abdominal sides is 6cm. The model is considered to be about 25 weeks gestation or more over the period for surgery. And its leg was floating and the head went to the bottom.

We set the manipulator around one abdominal side of the model from back and bent the hook-like mechanism to suit the abdominal sides, keeping away from fetal navel. After the end-effector bent to the beneath of the other side, the balloon was inflated with water, taking about 70 second. Then the mechanism for adjusting the holding plane was controlled to keep the fetus stable. The balloon suited the abdominal sides and supported the fetus without touching the frames of the manipulator (Fig.9).

However, the clips broke the covering part on the balloon when they were loose and then the balloon partially slipped away from manipulator.

2) We carried out another simulation more close to the clinical procedure with fetus model in uterus model in target period. The manipulator was inserted with balloon through a hole into the uterus model around the abdominal side of the fetus model. Although we tried to bend the hook-like mechanism below the chest of the fetus, it was hard because the density of the model was larger than water and sank down. We supported the fetus by hand from outside of the uterus and bent the mechanism to the other abdominal side. Then the

balloon was inflated by water.

It was not stable to support the fetus because the width between tip and root frame was large to the fetal sides when manipulator was bent 180 degree, that is the area of contact between the balloon and the fetus is small. But it became stable when put the fetus between the balloon and the uterine wall (Fig.10). The balloon prevented the contact between fetal chest and frame as first experiment, but fetal limb touched the frame from side, where the balloon did not swell.

3) Similar simulation using a larger fetus model in uterus model as above also has done. The fetus model used for simulation experiment is about 30 weeks. Since the model is floating in the water, it is not difficult to bend the hook-like mechanism under the fetus. We controlled bending angle of about 150 degree to fit the fetus size and then support the fetus.
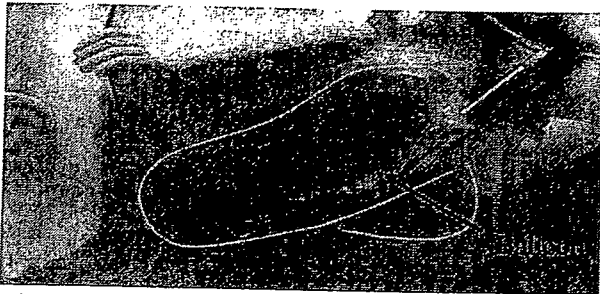


Fig. 9. Manipulator supporting fetus model in water. Manipulator stabilized fetus model without contact of fetus and frames.
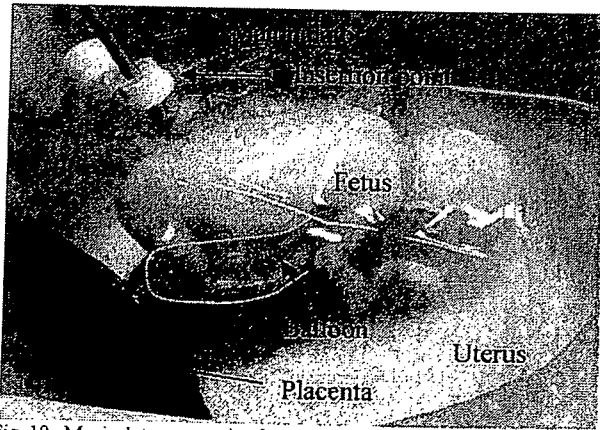


Fig. 10. Manipulator supporting fetus model in simulated uterus model.

### D. Ultrasound guided manipulator implementation

We evaluated the feasibility of ultrasound guidance for the manipulator. We put ultrasound probe on water surface and took images of manipulator's bending motion and the inflated balloon.

The manipulator and its bending motions were visible, but the position of the end-effector in 3D space was not easily realized, especially when hook-like mechanism was bending (Fig.11). Condition under the manipulator was not sufficiently shown. On the contrast, the inflated balloon was clearly visible as well as we could measured its diameter.

## IV. DISCUSSION

### A. Mechanical performance of manipulator

The main cause of the bending angle error on the hook-like mechanism was that the wire slack around 0 degree. After reeling up the slack, the slop change of bending angle fits the theoretical one. We can make the error smaller by straining the wires at beginning. In spite of large error, the standard deviation of bending angle was within 1 degree. The bending performance of the mechanism for adjusting holding plane was almost fit the theoretical one and the standard deviation was 2.5 degree. The accuracy of the mechanisms would be sufficient to operate under the guidance of ultrasound or fetoscope and problems on manipulation can be resolved by calibration.

The path of the tip of the hook-like mechanism in bending was smaller than that of each joint's evenly bending, and its hysteresis error was about 4 mm, which reduced the risk that manipulator contacts placenta in bending and recovering to straight form.

### B. Generative force of the balloon

Although it is not uncertain how large load the fetus is given in surgery, whole load-bearing power of 500 gf is thought to be enough to support. Partly load-bearing power of 100 gf is equal to 3.1 kPa, which is smaller than viscoelasticity of fetal (rat's) skin of 4 kPa [12]. The experiment showed possibility of supporting the fetus without injuring by the balloon.

We should measure the load on the fetus in clinical cases for some methods of covering exposed spinal cord, such as suturing and patching, in order to judge the usefulness of the
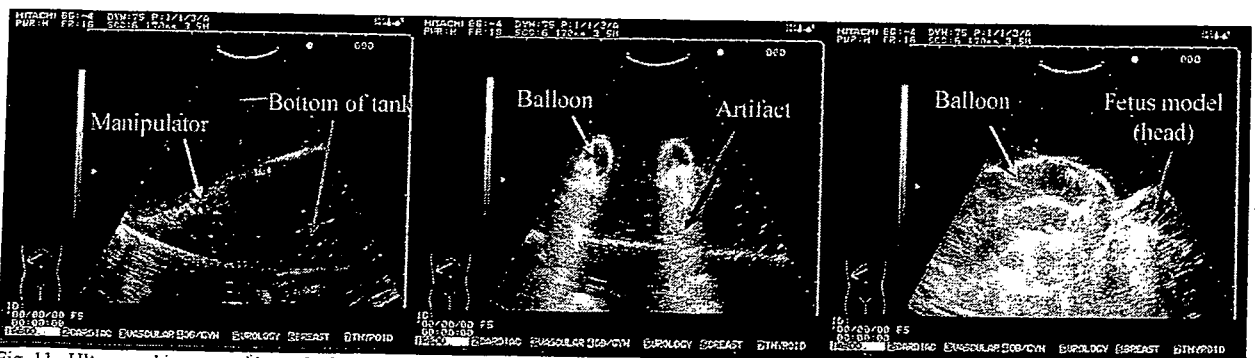


Fig. 11. Ultrasound images guidance. Left: manipulator with balloon folded. Center: inflated balloon. Right: manipulator supporting fetus model.

balloon clearly. And its outcome may indicate an appreciate method to the manipulator.

### C. Performance on phantom test

The developed manipulator was possible to support fetus model stability in first and third experiment. The supporting method may be useful to stabilize the fetus. The manipulator has an ability to support fetus of various size about 25-30 weeks gestation. However, the width between the tip and root frame of the hook-like mechanism is large to the fetus in 19-24 weeks gestation. In order to fit the target fetuses, the width should be smaller.

The clip might be unsuitable to fix the balloon, for it broke the covering part on the balloon. New structure of balloon without clip should be developed, such as a balloon folding not only upside of frames but also around frames. It can keep fetus off the side and beneath of frames.

On the second experiment, we supported the fetus model by hand from outside of the uterine wall because it sank down and there was no space under the fetus for the manipulator. It would be hard to do so under ultrasound or fetoscopic image in clinical usage. The density of the fetus is important factor to consider a procedure to hold it. We should arrange more real environment.

### D. Ultrasound guidance

The ultrasound could visualize the manipulator and the balloon. Since we could measure the diameter of balloon, ultrasound can be also available to estimate the pressure of the balloon. In order to visualize the sight hidden by artifact under the manipulator, fetoscope is also need. Since the ultrasound image of 2D gave limited information of relation between fetus and manipulator in space, we will use 3D ultrasound guidance.

### E. Prospects for clinical application

The diameter of the manipulator is 8 mm now, but it has to be much smaller to reduce the risk of complications. We aim to develop smaller one which can pass trocar for fetal surgery. Therefore we try to develop the holding unit of diameter 4 mm, excluding balloon. We are sure that we can develop it since the mechanisms of the manipulator are not so complex. The user interface on PC is not ease to operate and needs extra hands, so we should equip manipulator with another user interface like handheld type. Furthermore we try to control the pressure of balloon, adding sensor to water injection unit.

## V. CONCLUSION

A manipulator to stabilize fetus, with large contact area by balloon and keeping away from the umbilical cord, for intrauterine surgery are reported in this paper.

The manipulator has two bending mechanisms, one driven by wires is for supporting fetus from beneath, and the other driven by linkages is for adjusting holding plane corresponding to insertion angle into uterus and a balloon which enables area for contact with fetus larger than the diameter of incision to support stably and softly. For clinical use, this manipulator can be divided into holding unit, driving power unit and balloon to meet sterilizations or disposal.

The accuracy of bending performances was sufficient to operate under guidance of ultrasound and fetoscope. The inflated balloon generated sufficient force to support the fetus and its softness showed possibility of not injuring fetus. The phantom experiment showed that the manipulator could stabilize fetus beneath without touching the umbilicus. These results indicated that this manipulator has potential to stabilize fetus in uterus softly.

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which are connected components of computer aided surgery system.

## 2. Methods

We use two devices: the projector-camera device and the optical tracking device. The projector-camera device identifies relative geometry among surgical surfaces in three dimensions, camera-image, and projector-image and then projects a desired image onto the surgical surface. An optical tracking device tracks the position of a probe which serves as Virtual-pen. Two devices are registered accurately and work as a single integrated system. To implement interactive functions of Virtual-pen, projection areas regard as menus are divided into several regions. Each region corresponds to pre-defined actions. The functions activated when Virtual-pen is laid in the regions.

## 3. Results

The position accuracy of Virtual-pen in three dimensional surfaces was 0.35 mm in maximum error, which is high enough for most surgical scenarios. Real-time geometric and radiometric compensation techniques enabled us to make the projected image undistorted even on dynamic surfaces such as human body. The optical tracking device was robust because it tracked Virtual-pen without interfering with operation illumination. Our experiments using a phantom of head in a laboratory environment demonstrated an acceptable quality and the clinical test will be performed to verify the practical value of the proposed system.

## 4. Conclusion

The proposed method enhanced the computer aided surgery system by eliminating the need of inadequate tools and by suggesting an interactive user interface. The position of surgical targets was exactly tracked by the optical tracking device and accurately was marked by direct-projected augmented reality technology. Predefined menus offered various functions dynamically and interactively. The implemented prototype would be integrated into the computer aided surgery system under development in Center for Intelligent Surgery System, Seoul, Korea.

## Acknowledgment

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## Development of wide–angle view 3D endoscope using wedge prisms

E. Kobayashi[a], Y. Takata[b], K. Ikebe[b], T. Sakurai[b], I. Sakuma[a]
[a]School of Engineering, The University of Tokyo
[b]School of Frontier Science, The University of Tokyo
**Keywords** Medical robot · 3D Endoscope · Wedge prism

## 1. Introduction

We have developed a wide-angle view laparoscope that enables the surgeon to control the FOV without moving the laparoscope itself. It is free from the risk of hitting internal organs due to laparoscope movement, and can realize safer robotically assisted laparoscopic surgery. Also, it can apply to other site which does not have enough space to move the endoscope. In this paper, we applied this mechanism to 3D endoscope and developed a new wide-angle view 3D endoscope.

## 2. Methods

We used a thin 3D endoscope (LS-501D, Shinko Optical Co. Ltd, Tokyo, Japan). Its diameter was 5.4 mm. Two 1/10 inch micro CCD cameras (270,000 pixels) were mounted on the tip. We mounted two wedge prisms at the tip. Each prism was attached to a sleeve and these rotate independently about the axis of the endoscope by motors. In this mechanism, only two sleeves rotate within the endoscope, so the mechanism can be simple and small and yet can observe a wide angle of view.

We used wedge prisms whose diameters are 12 and 8.5 mm. Total diameter of the wide-angle view 3D laparoscope was 14 mm. For the light source, we made a special tube with a fiber. The outer

diameter of the tube was 18 mm and inner diameter was 14 mm, so that it could inset into the commercialized trocar (ENDO-PATH Large-Port Trocar, Ethicon). It illuminated the entire moving view range of the endoscope. The material of the prism was LAL18 whose refractive index was 1.7 and wedge angle was decided 10°.

## 3. Results

The system could bend the light axis in a cone with a vertex angle of approximately 14.5° under the conditions that view angle of the 3D endoscope was 76°.

We evaluated the depth perception of the wide-angle view 3D endoscope qualitatively. We put the two wedge prisms on the tip of the 3D endoscope, and rotate these prisms. Volunteers observed the 3D endoscopic image and tried to grasp objects by forceps. As a result, the volunteers could get the depth perception without sense of discomfort and grasp the object easily. Also, although a little distortion in the image was observed, there was no degradation by prisms.

## 4. Conclusion

We have developed the 3D wide angle view endoscope using wedge prisms. Bending view angle was 14.5°. In the qualitative evaluation of depth perception, volunteers could get the depth perception without sense of discomfort.

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## FOV—changeable endoscope using a beam splitter

Keri Kim[a], Kiyoshi Matsumiya[a], Ken Masamune[a],
Takeyoshi Dohi[a]
[a]Graduate School of Information Science and Technology,
The University of Tokyo, Japan
**Keywords** Endoscopic surgery · Minimally invasive surgery · Beam splitter · Field of view · Polarization plate

## 1. Introduction

Minimally invasive surgery is becoming more common nowadays. One of the important fields of minimally invasive surgery is endoscopic surgery. In the endoscopic surgery, it is very important to manipulate the endoscope smoothly so that the surgeon can observe where he or she wants to see. In addition, during the operation the surgeon has to manipulate the endoscope safely not to damage body tissues or internal organs.

In the surgery of twin to twin transfusion syndrome, the front view needs to be observed to insert the endoscope safely, and after the proper insertion we need to observe the diseased area which can be the front side or lateral side. How to observe lateral view safely? To solve this problem, we have suggested the endoscope system that can be used to observe the front side and the lateral side without moving or bending the whole endoscope system.

## 2. Methods

In this endoscope system, the field of view can be changed using a beam splitter and two polarization plates. The endoscope system consists of a CCD camera with the inner sleeve and the outer sleeve.

A beam splitter is attached at the distal tip of a CCD camera which is mounted inside of the inner sleeve. The inner sleeve has a polarization plate at the distal tip and observation window at the lateral side. The outer sleeve has a polarization plate at the distal tip and observation window at the lateral side, also.

Inserting the inner sleeve into the outer sleeve, we can observe the front view through the polarization plates with the observation window closed. And also we can observer the lateral view through the observation window by rotating the outer sleeve. At this time the front view can not be observed by the polarization plates.

We made a prototype of the FOV-changeable endoscope. The experiment on changing field of view was conducted using the prototype.

## 3. Results and conclusion

The endoscope prototype has 10 mm in diameter including illumination. Two polarization plates seem to degrade the brightness of the front view. In the lateral view, the observation is made through the observation window, so there is no degradation of the brightness. So we used the beam splitter which has 70 percent transmission and 30 percent reflection.

In the experiments using the prototype, the field of view was changed by rotating the outer sleeve without moving the endoscope itself, so the operation can be conducted safely. Also, there are some kinds of operation which need to use the rigid endoscope and lateral view endoscope also. In these kinds of operation, the surgeon has to switch two or three types of endoscope. But using our method the surgeon does not have to switch the endoscope thus the operation time can be reduced and the sterilization can be conducted more easily.

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## Influence of oscillation of an electronic OR-microscope on neurosurgical preparation quality

W. Lauer[a], S. Serefoglou[a], M. Engelhard[b], B. Ibach[a], K. Radermacher[a]

[a]Chair of Medical Engineering, Helmholtz-Institute for Biomedical Engineering, RWTH Aachen University, Germany
[b]Department of Neurosurgery, Ruhr-University Bochum, Germany

**Keywords** Neurosurgery · Oscillation · Microscope · Camera · HMD

### 1. Introduction

Oscillation is a major problem for operating microscopes. An oscillating picture of the operating field puts stress onto the surgeon and is therefore likely to lead to a higher probability of inaccuracy and faults. During the development of a novel visual support-system for endoscopically-assisted neurosurgical interventions the influence of camera-oscillation on the quality of preparation has been of high importance. In this framework the electronic microscope ("exoscope") is handled by a telemanipulation-platform and the acquired images are presented to the surgeon by a Head-Mounted-Display (HMD) without any physical contact between surgeon and camera (http://www.minop.de).

### 2. Methods

In a first test conventional OR-microscopes were analyzed to determine clinically accepted state-of-the-art values for intraoperative oscillation.

In a second test neurosurgeons had to rate pattern-visibility and to fulfill preparation tasks in a virtual test environment. Special line- and point-preparation tasks had to be performed using a tracked pointer, images were acquired by a virtual oscillating camera and displayed via HMD. Additionally the test-persons (7 neurosurgeons) had to repeatedly state their actual subjective discomfort on a standardized rating scale to identify the influence of the preparation conditions on the strain level.

### 3. Results

The field tests concerning the oscillation of commercial OR-microscopes showed deceleration times of 2–3 s at oscillation frequencies of about 1 to 1.5 Hz.

Rating the visual differentiability of the virtual test-patterns under various oscillation-conditions the surgeons determined an allowable frequency limit of 4 Hz and allowable amplitudes of up to four times the width of the viewed structure.

Concerning preparation quality a significant reduction of preparation deviation with increased zoom factor, a significant increase of preparation deviation with increased frequency and a highly significant increase of preparation deviation with increased amplitude were identified.

Throughout the test-cycle the discomfort statements on the rating scale increased with a saturation characteristic.

### 4. Conclusion

The virtual tests showed a clear negative influence of camera-oscillation on the preparation quality and helped to define demands for the concept and realization of the developed exo-scope-telemanipulation-platform. However, it has to be taken into account that these results have been achieved using a specific experimental setup (HMD, graphics hardware, simplified tasks, etc.) and will therefore have to be further evaluated with the realized demonstrator-system and under real OR-conditions.

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## Calculation and visualization of trocar positions for abdominal minimally invasive surgery

C. Schönfelder[a], L. A. Kahrs[a], T. Stark[a], J. Raczkowsky[a], H. Wörn[a]

[a]Institute for Process Control and Robotics, University of Karlsruhe, Germany

**Keywords** Augmented reality · Computer-assisted surgery · Minimally invasive surgery · Port planning

### 1. Introduction

For minimally invasive surgery the placement of the trocars is a decisive factor for the success and the straightforwardness of an intervention. Poor choices for trocar positions often result in prolonged operation times or the need to introduce additional ports. Preoperatively planning of the trocar positions will help solving this problem. For abdominal minimally invasive surgery the insufflation of the patient prevents the direct use of the computed positions because the planning is generally performed with a regular patient model (i.e. without insufflation). We present a system for the visualization of the optimal port positions onto the patient's abdomen for minimally invasive surgery that deals with this issue.

### 2. Methods

The preoperative input for our system is a reference surface model of the patient (e.g. obtainable through a segmented ct-scan) and the trocar positions and orientations that have been planned with respect to this model. The visualization of the trocar positions is done by direct projection onto the abdomen using projection based augmented reality techniques. The projector system has two attached cameras and the complete setup is photogrammetrically calibrated. For the registration a surface scan based on a projected coded light pattern is acquired from the abdomen of the patient at the beginning of the treatment. This scan is used to register the patient to the preoperatively obtained model. After the patient has been insufflated a second scan of the abdomen is performed. The acquired surface model is then used to modify the preoperatively planned port positions. In the simplest case—each port is used to access only a single target area—the correct trocar locations are calculated as intersection between the insufflated surface and the lines defined by the planned trocar position and the respective target location.

### 3. Results

The system was evaluated with a torso phantom that supports the simulation of an insufflated abdomen with a maximal insufflation height of 5 cm. A target and several port positions were planned on a reference surface model. The trocar positions were projected on the phantom and recorded with a high precision measurement arm for the regular and the insufflated case. The overall position error was below 3 mm which led to an orientation error of less than 2°.

### 4. Conclusion

A system for the visualization of trocar positions for abdominal minimally invasive interventions was presented and the evaluation with a phantom showed acceptable accuracy. Intraoperative trials, which are planned for the immediate future, will show if this accuracy can be achieved in the operation theatre.
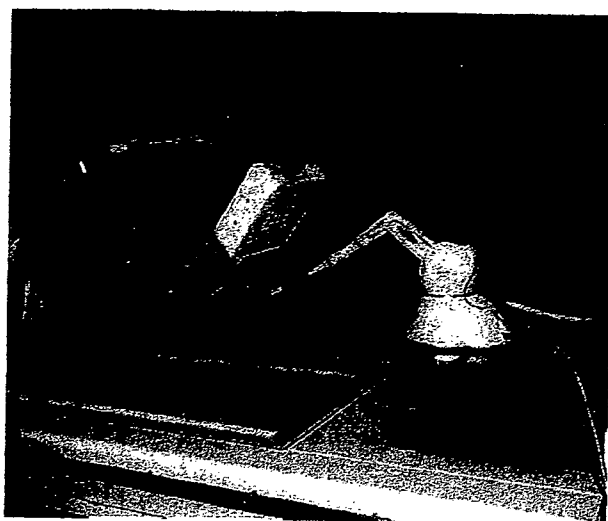
Fig. 1 The lab setup of the system

artificial data set. Uniform noise (0.5 mm) was added to the grid points to ensure that the grid was non-regular. The non-linear deformation of the mesh in the z-dimension was governed by the following equation ($A = 10$, $B = 0.7$):

$$f(z) = f(z-1) - A \times (\exp(B \times (z/z\_max) - 1)$$
$$/(\exp(B) - 1)|f(0) = 0,$$

where $z$ denotes the index in the $z$-dimension and $z\_max$ denotes the maximum index in the $z$-direction. This set of deformed points constituted the points in the Aurora-frame. A rigid transformation $R(100, -70, 50, \pi/4, 0, 0)$ determined the positions of the grid points of the basic mesh in the Phantom frame. A global transformation $T1$ was computed by SVD using the corresponding data points from the Aurora- and Phantom-frames. The volume embedded by the deformed mesh was uniformly sampled at 600 positions and the sampled positions were corrected by the dewarping algorithm as well as by $T1$. Table 1 summarizes the results of comparing the computed positions with the real positions. Two datasets were used to assess the accuracy of the system

3.2 Dataset 2

Table 1 Summary of the accuracy tests performed with the artificial data set (dataset 1) and the dataset acquired in the operating room (dataset 2)

| Test | Points | RMS (mm) | Mean (mm) | Standard deviation (mm) |
|---|---|---|---|---|
| Dataset 1 corrected by dewarping | 600 | 1.10 | 0.96 | 0.53 |
| Dataset 1 corrected by $T1$ | 600 | 7.06 | 6.54 | 2.67 |
| Dataset 1 corrected by $R$ | 600 | 3.98 | 2.95 | 2.67 |
| Dataset 2 corrected by dewarping | 600 | 1.32 | 1.29 | 0.29 |
| Dataset 2 corrected by $T2$ | 600 | 20.77 | 18.43 | 9.56 |

$T1$ and $T2$ denotes the global transforms computed for dataset 1 and dataset 2, respectively. $R$ denotes the real rigid transform which models the relation between the Aurora and Phantom frame
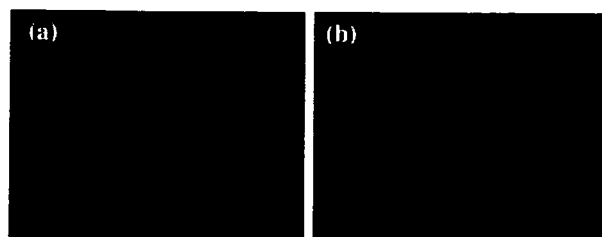
Fig. 2 a Visualization of dataset 2. b Dataset 2 after using the dewarping algorithm

A second dataset ($11 \times 11 \times 7$ with a resolution of 10 mm) was collected on top of an operating table in an operating room (OR) using the dewarping algorithm (see Fig. 1). To evaluate the accuracy of the algorithm using this dataset, the same physical volume embedded by dataset 2 was uniformly sampled at 600 points with the Phantom. A global rigid transformation $T2$ was computed by SVD using all the 600 point sets. Table 1 summarizes the results of comparing the positions computed by the dewarping algorithm, as well as when using $T2$, with the real position of the Phantom. Figure 2 shows the grid sampled in the Aurora-frame on the left, and the corrected grid in the Phantom frame on the right.

3. Conclusion

Electromagnetic tracking is for many clinical applications the only suitable choice of tracking system. However, in the presence of certain materials the accuracy of the system can degrade considerably. We have presented a general system which can detect and improve on these inaccuracies by using a portable and inexpensive haptic device. The main advantages being that the system is highly portable, inexpensive and can correct tracking signals in real-time. However, the system is not able to correct for dynamic inaccuracies, for instance correcting for magnetic distortions due to introduction of surgical instruments. Another restriction arises when using local rigid transformations to construct a global deformation field. This results in a non-regularized deformation field which might lead to non-continuous tracking at the hexahedron boundaries.

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Development of placenta mapping system for treatment of twin-to-twin transfusion syndrome (TTTS)

Tua Namora Nainggolan[a], Hongen Liao[b], Etsuko Kobayashi[b], Toshio Chiba[c], Ichiro Sakuma[b]
[a]Graduate School of Frontier Sciences, University of Tokyo
[b]Graduate School of Engineering, University of Tokyo
[c]National Center for Child Health and Development, Japan

Abstract Connecting vessels occurred in twin-to-twin transfusion syndrome (TTTS) cause an imbalanced blood flow between twins. Laser photocoagulation treatment as one of useful method has