Eye-hand Coordination Problems during Minimally Invasive Surgery; 
from theory to clinical solution

Mark Wentink
Delft University of Technology
Faculty of Engineering and Design
Man-Machine Systems & Control Group
MISIT1
Mekelweg 2, 2628 CD, Delft
The Netherlands
m.wentink@wbmt.tudelft.nl

Abstract

During Minimally Invasive Surgery the surgeon has an indirect sight on the operating area which is presented on a monitor somewhere in the Operating Room. The displayed operating area is spatially remote from the physical operating area. The surgeon experiences reduced depth perception and a hampered eye-hand coordination. Eye-hand coordination is disturbed because the displayed instrument movements on the monitor do not correspond with the initial movements that are executed by the hand (compare this with writing your name while looking into a mirror). In this paper eye-hand coordination is modelled from a system theoretical point of view as a guidance & control problem. Guidance is provided by the visual system while the proprioceptive system provides the actual control of the hand. It is outlined that, according to the proposed model, correct eye-hand coordination depends on an accurate estimate of the transformation of seen (visual) to felt (proprioceptive) positions and movements. This transformation is modelled by a transformation matrix in the eye-hand coordination model. It is shown that this transformation matrix is far more complex, and therefore difficult to learn, in Minimally Invasive Surgery as compared to daily life. The proposed eye-hand coordination model is successfully used to extract some theoretical solutions to improve eye-hand coordination. One of the solutions extracted with the model is the rotation of the endoscopic camera such that directions of instrument movement of the displayed and the real instrument correspond. This solution has been evaluated experimentally. The experiment revealed that the rotation of the endoscopic camera until the directions of movement correspond significantly improves eye-hand coordination.

Keywords Minimally Invasive Surgery, eye-hand coordination model, camera-rotation

Introduction

Since the invention of miniature, high quality, CCD-cameras around the year 1984, Minimally Invasive Surgery (MIS) has become daily practice in many hospitals around the world. Nowadays almost all gallbladder removals (cholecystectomy) and many other operations are performed minimally invasively [Brooks, 1998].

1. This research is part of the Minimally Invasive Surgery and Interventional Techniques (MISIT) program of the Delft Interfaculty Research Center on Medical Engineering (DIOC-9).
During MIS in the abdomen the surgeon operates through 3 or 4 small incisions (~15 mm) with long and slender instruments. Visual feedback from the operating area, and thus the instrument tips, is provided by an endoscope which is inserted into the patient through one of the incisions. An endoscope is a long, tube shaped lens system with a diameter of 5 or 10 mm on which a small CCD-camera is mounted. Operating space around the pathological tissue that has to be operated on is created by insufflating the abdomen with CO₂ gas. During the operation the surgeon looks at a monitor situated in the Operating Room (OR) on which real time images provided by the endoscope are presented. Figure 1 shows a minimally invasive gallbladder removal.

![Figure 1: Surgeon and camera-assistant performing a minimally invasive gallbladder removal. The endoscopic camera picture at which the surgeon (left) and the camera-assistant (right) are looking is also shown.](image)

Advantages of minimally invasive surgery over conventional open surgery are:

1. less damage to the skin
2. reduced risk of infection
3. shorter recovery time and hospital stay

Although minimally invasive surgery has many benefits for the patient it is a far more difficult operating technique for the surgeon [Tendick, 1993]. The indirect way of operating through incisions and the spatial remoteness of the operating area pose a number of problems to the surgeon:

1. reduced depth perception due to the use of a 2D-endoscope and 2D-monitor
2. difficult eye-hand coordination due to the indirect sight on the instrument tips
3. reduced manipulation dexterity due to reduced tactile and proprioceptive feedback
4. scaling, mirroring and reduced degrees of freedom of movements of the instrument tips because the incision acts as a spherical joint

This paper focuses on the problems and possible solutions associated with the difficult eye-hand coordination during MIS.

Especially surgical residents need a rather long training period to adapt to the difficult eye-hand coordination. Surgical residents may benefit from aids that improve eye-hand coordination. Furthermore, skilled surgeons can improve their task efficiency when the negative effects are reduced [Cuschieri, 1995].

The aim of this paper is twofold. The first aim is to identify the mechanisms behind eye-hand coordination during MIS from a system theoretical point of view. Eye-hand coordination is
modelled as a guidance & control problem in this paper. Secondly, this paper aims at deriving a clinical solution from the theory that would improve eye-hand coordination.

In this paper a model which describes eye-hand coordination as a guidance & control problem is outlined. The disturbed eye-hand coordination during MIS is theoretically described by the addition of a number of subsystems in the guidance & control model. Some theoretical solutions to improve eye-hand coordination during MIS and an experimental evaluation of one of those solutions (endoscopic camera-rotation) are described also. This paper ends with a number of conclusions.

**Theoretical model of eye-hand coordination**

During our life we have learned to perform all kinds of tasks with the hands and with tools that act as a functional extension of the hands (e.g.: fork, knife and spoon). Most of the time, and especially while learning to perform a new task, we are looking down on the hands to guide hand movements. Therefore it seems reasonable to assume that the reference trajectories which the Central Nervous System (CNS) applies to carry out a given task are defined with respect to a visual reference frame $\Psi_{vis}$. For example, if we want to pick up a cup of coffee we first have to move our hands towards the cup before we can close our hands around it. A possible reference trajectory for this task could be the decreasing amount of visual background between the hand and the cup of coffee and the relative visual size of the hand and the cup of coffee. Once there is no background between the hand and the cup of coffee any more and the relative sizes correspond, then the hand can be closed to pick up the cup of coffee.

The visual reference frame $\Psi_{vis}$ is equal to the reference frame in which the visual system (eyes and visual cortex) perceives visual information from our environment. Within the scope of this paper it is not necessary to further quantify the visual reference frame.

Hand movements are guided by the visual system, however, the proprioceptive system is responsible for actually controlling the hand with a certain velocity to a desired position. Position and velocity are perceived by the proprioceptive system with respect to a reference frame $\Psi_{prop}$. In general, the perception of hand movement by the proprioceptive system is faster than the perception of hand movement by the visual system [Martin, 1995].

In Figure 2 a system theoretical eye-hand coordination model is proposed in which the proprioceptive and the visual system are incorporated as observers in a control loop and a guidance loop, respectively. Eye-hand coordination is modelled as a guidance & control problem. Force feedback is not (yet) incorporated in the model proposed here.

The input of the model in Figure 2 is a TASK which is then translated into reference signals $(u_{ref}, \dot{u}_{ref})$ with respect to the visual reference frame by the subsystem internal representation of task.

The system to be controlled by the two feedback loops is the hand+instrument system. The outputs of this dynamic system are position, velocity and acceleration defined in a hand and an instrument reference frame ($\Psi_{hand}$ and $\Psi_{instr}$). The transformation matrix $^{1}\mathbf{Q}_{hand}$ represents the kinematic link between the hand and the instrument (this matrix would be the $C$ matrix in

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1. In general a transformation matrix $^{1}\mathbf{T}_{2}$ transforms reference frame $\Psi_{1}$ to $\Psi_{2}$ [Craig, 1989]
a state space description of the hand+instrument system). If the instrument and the hand are rigidly connected (i.e. the hand holding a rigid knife) then \( T_{\text{hand}}^{\text{instr}} \) equals the identity matrix.

The proprioceptive and the visual system are modelled by two constant transformation matrices, \( T_{\text{hand}}^{\text{prop}} \) and \( T_{\text{vis}}^{\text{vis}} \), which transform the hand fixed reference frame \( (\Psi_{\text{hand}}) \) to the proprioceptive reference frame \( (\Psi_{\text{prop}}) \) and the instrument fixed reference frame \( (\Psi_{\text{instr}}) \) to the visual reference frame \( (\Psi_{\text{vis}}) \), respectively. Dynamics of the proprioceptive and visual system are neglected. \( K_{\text{guid}} \) and \( K_{\text{cont}} \) represent the feedback gains in the guidance and control loop, they can also be interpreted as weighting matrices on visually and proprioceptively perceived positions and velocities. The transformation matrix \( T_{\text{vis}}^{\text{vis}} \) must be added after the subtraction point in the guidance loop to assure that the signals that are compared at the subtraction point in the control loop are defined in the same reference frame. Writing out the transformation from the hand reference frame to the proprioceptive reference frame for both loops yields the following equation (at the subtraction point in the control loop):

\[
T_{\text{hand}}^{\text{prop}} \Psi_{\text{hand}} = T_{\text{vis}}^{\text{vis}} T_{\text{instr}}^{\text{instr}} T_{\text{hand}}^{\text{hand}} \Psi_{\text{hand}}
\]

control loop guidance loop

Rewriting Eq. 1 yields:

\[
T_{\text{vis}}^{\text{vis}} = T_{\text{hand}}^{\text{prop}}(T_{\text{instr}}^{\text{instr}} T_{\text{hand}}^{\text{hand}})^{-1}
\]

with

\[
(T_{\text{instr}}^{\text{instr}} T_{\text{hand}}^{\text{hand}})^{-1} = T_{\text{instr}}^{\text{instr}} T_{\text{vis}}^{\text{vis}}
\]

\[
\Rightarrow T_{\text{vis}}^{\text{vis}} = T_{\text{prop}}^{\text{prop}} T_{\text{hand}}^{\text{hand}} T_{\text{instr}}^{\text{instr}} T_{\text{vis}}^{\text{vis}}
\]
The transformation matrix $T^\text{prop}$ represents the kinematic link between 'seen movements of the instrument' and 'felt movements of the hand'. During everyday life $T^\text{prop}$ meets Eq. 2, and proprioceptive controlled directions of movement of the hand correspond to subsequently seen directions of movement of the instrument. The hand and instrument move in a *coordinated* manner. Notice that since $T^\text{vis}$ also depends on $T^\text{instr}_\text{hand}$, the transformation matrix $T^\text{prop}$ has to be learned again every time a new instrument with new kinematics is used.

A correct estimate of the matrix $T^\text{prop}$ in the CNS is the essence of coordinated instrument movements and thus good eye-hand coordination.

Control signals which eventually go into the subsystem *hand+instrument* are transformed to the hand reference system ($\Psi^\text{hand}_\text{vis}$) by the transformation matrix $T^\text{prop}$. This transformation matrix equals $(T^\text{prop}_{\text{hand}})^{-1}$, and represents knowledge about the proprioceptive system.

In the next section the eye-hand coordination model proposed in Figure 2 is extended to the situation in which a surgeon operates minimally invasively. It will become clear that the addition of several subsystems in the guidance loop requires an altered matrix $T^\text{prop}_{\text{vis}}$ in order to maintain coordinated instrument movements.

**Eye-hand coordination model during Minimally Invasive Surgery**

The eye-hand coordination model in Figure 2 can also be extended to instrument manipulation during MIS by adding the subsystems *endoscope* and *monitor* in the visual guidance loop. In Figure 3 an eye-hand coordination model which models instrument manipulation during MIS is proposed.

![Figure 3: Closed-loop eye-hand coordination model with inner control loop (proprioceptive system) and outer guidance loop (visual system) in case of MIS. Notice that the surgeon is looking at a monitor to see instrument movements, the visual system therefore makes the transformation $T^\text{vis}_{\text{mon}}$.](image)

Movements of the hand are kinematically transformed by the incision to movements of the instrument. Movements of the hand are mirrored and scaled by the incision. In general a transformation matrix $T$ has the following form:
\[
T = \begin{bmatrix}
R & p \\
0 & 1
\end{bmatrix}
\]

\[T \in \mathbb{R}^{4 \times 4}, R \in \mathbb{R}^{3 \times 3}, p \in \mathbb{R}^3\]

here \(R\) is a rotation matrix which aligns two reference frames and \(p\) is a translation vector which translates the origin of one reference frame to another. In case of the transformation from hand movement to instrument movement the transformation matrix \(T_{hand}\) can have the following form:

\[
T_{hand}^{instr} = \begin{bmatrix}
R_{instr}^{hand} & p_{hand}^{instr} \\
0 & 1
\end{bmatrix} = \begin{bmatrix}
-1 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & 1 \times A \\
0 & 0 & 0
\end{bmatrix}
\]

Where the negative factors represent the mirroring effect and the variable \(A\) represents the scaling effect.

The subsystems endoscope and monitor are modelled by the transformation matrices \(T_{end}^{instr}\) and \(T_{end}^{monitor}\), respectively. These transformation matrices transform instrument movements from the instrument reference frame via the endoscope reference frame to the monitor reference frame.

Previous it was stated that a correct estimate of the matrix \(T_{vis}^{prop}\) in the CNS is the essence of good eye-hand coordination. This transformation matrix can be derived for the eye-hand coordination model during MIS by rewriting Eq. 1:

\[
\begin{bmatrix}
T_{vis}^{prop} \\
T_{mon}^{vis} \\
T_{end}^{mon} \\
T_{instr}^{end} \\
T_{hand}^{hand}
\end{bmatrix} = \begin{bmatrix}
T_{vis}^{hand} \\
T_{mon}^{vis} \\
T_{end}^{mon} \\
T_{instr}^{end} \\
T_{hand}^{hand}
\end{bmatrix}
\]

Rewriting Eq. 5 yields:

\[
T_{vis}^{prop} = T_{hand}^{prop} (T_{mon}^{vis} T_{end}^{mon} T_{instr}^{end} T_{hand}^{hand})^{-1}
\]

with \( (T_{mon}^{vis} T_{end}^{mon} T_{instr}^{end} T_{hand}^{hand})^{-1} = T_{instr}^{hand} T_{end}^{mon} T_{mon}^{vis} \)

\[\Rightarrow T_{vis}^{prop} = T_{hand}^{prop} T_{instr}^{hand} T_{end}^{mon} T_{mon}^{vis} \]

From Eq. 6 it can be seen that in case of MIS the kinematic link between 'seen movements of the instrument' and 'felt movements of the hand' represented by \(T_{vis}^{prop}\) in Eq. 6 is much more complicated than the kinematic link during normal eye-hand coordination where there exists a direct line-of-sight with the instrument (Eq. 2). During MIS correct eye-hand coordination is severely hampered.
Theoretical solutions to improve eye-hand coordination

From the previous two sections it has become clear that coordinated hand movements (eye-hand coordination) depend on a correct estimate of the transformation matrix $T_{vis}$. It was shown that in case of a direct line-of-sight from the eyes to the instrument the transformation matrix equals:

$$ T_{vis}^{\text{direct}} = T_{hand}^{prop} T_{instr}^{hand} T_{vis} $$

During MIS, however, this transformation matrix is much more complicated, in the previous section the transformation matrix $T_{vis}^{\text{MIS}}$ during MIS was derived:

$$ T_{vis}^{\text{MIS}} = T_{hand}^{prop} T_{instr}^{hand} T_{end}^{instr} T_{mon}^{end} T_{vis}^{mon} $$

The effects of the incision and of the indirect line-of-sight are pointed out separately in Eq. 8. At the level of the transformation matrices there are two theoretical solutions to solve the problem of disturbed eye-hand coordination.

Solution 1:
If $T_{vis}^{\text{indirect}}$ is brought back to a form in which it is easier to learn (identify) by the CNS, then eye-hand coordination during MIS might improve, or at least be easier to learn. An example of a transformation matrix that is probably easy to learn is a matrix with a lot of zeros (like the matrix in Eq. 4).

Solution 2:
Eye-hand coordination during MIS is improved if $T_{vis}^{\text{indirect}}$ is equal to $T_{vis}^{\text{direct}}$, which is a transformation matrix that has been firmly established during everyday life while having a direct line-of-sight.

Solution 2 can also be represented mathematically by the following equation:

$$ T_{vis}^{\text{indirect}} = T_{hand}^{prop} T_{instr}^{hand} T_{vis}^{direct} $$

In Eq. 9 the transformation $T_{hand}^{prop}$ is equal for the direct and the indirect case and can thus be eliminated from the equation. Eq. 9 is simplified by dividing it into two equations, this yields a possible solution:

$$ T_{hand}^{direct} = T_{hand}^{indirect} $$

AND

$$ T_{vis}^{direct} = T_{end}^{end} T_{mon}^{mon} T_{vis}^{indirect} $$

Now the disturbed eye-hand coordination during MIS is divided into two negative effects. The first effect describes the difficult transformation from hand movements to instrument movements due to the incision. The second effect describes the difficult transformation from real instrument movements to perceived instrument movements.
f the two negative effects in Eqs 10a and 10b are compared than it is clear that the second negative effect involves a far more difficult transformation than the first negative effect. A trivial solution which solves Eq. 10b can be obtained by aligning the endoscope and monitor reference frames with the visual reference frame, or:

\[ \Psi_{\text{end}} = \Psi_{\text{mon}} = \Psi_{\text{vis}} \]

his yields:

\[ T_{\text{mon}} = I, \quad T_{\text{vis}}^{\text{mon}} = I, \quad T_{\text{vis}}^{\text{end}} = T_{\text{instr}}^{\text{end}} \]

\[ \Rightarrow T_{\text{vis}}^{\text{instr}} \bigg|_{\text{direct}} = T_{\text{vis}}^{\text{instr}} \cdot I \cdot I = T_{\text{vis}}^{\text{instr}} \bigg|_{\text{indirect}} \]

From Eq. 12 it can be seen that aligning the reference frames (Eq. 11) reduces the eye-hand coordination problem; the transformation matrix is equal for direct and indirect sight on the instrument. However, during MIS this solution is often not feasible, because the camera-assistant holding the endoscope would hamper the surgeon in his movements if the endoscope is aligned with the visual reference frame of the surgeon [Breedveld, 1998].

Figure 4: Camera-assistant hampers the surgeon if he aligns the endoscope reference frame (fixed to the endoscope) with the visual reference frame (fixed to an eye of the surgeon). Adopted from Breedveld, 1998.

Another solution for the second negative effect can be found by writing out Eq. 10b according to the definition of a transformation matrix given by Eq. 3:

\[
\begin{bmatrix}
R_{\text{vis}}^{\text{instr}} & P_{\text{vis}}^{\text{instr}} \\
0 & 1
\end{bmatrix}
_{\text{direct}} =
\begin{bmatrix}
R_{\text{end}}^{\text{instr}} & P_{\text{end}}^{\text{instr}} \\
0 & 1
\end{bmatrix}
_{\text{direct}} \cdot
\begin{bmatrix}
R_{\text{end}}^{\text{mon}} & P_{\text{end}}^{\text{mon}} \\
0 & 1
\end{bmatrix}
_{\text{indirect}} \cdot
\begin{bmatrix}
R_{\text{mon}}^{\text{mon}} & P_{\text{mon}}^{\text{mon}} \\
0 & 1
\end{bmatrix}
_{\text{indirect}}
\]

\[
\begin{bmatrix}
R_{\text{vis}}^{\text{instr}} & P_{\text{vis}}^{\text{instr}} \\
0 & 1
\end{bmatrix}
_{\text{direct}} =
\begin{bmatrix}
R_{\text{end}}^{\text{instr}} & R_{\text{end}}^{\text{mon}} & R_{\text{mon}}^{\text{mon}} \\
0 & 1
\end{bmatrix}
_{\text{indirect}} \cdot
\begin{bmatrix}
R_{\text{end}}^{\text{instr}} & R_{\text{end}}^{\text{mon}} & R_{\text{mon}}^{\text{mon}} \\
0 & 1
\end{bmatrix}
_{\text{indirect}} \cdot
\begin{bmatrix}
R_{\text{mon}}^{\text{mon}} & P_{\text{mon}}^{\text{mon}} + P_{\text{end}}^{\text{instr}} \\
0 & 1
\end{bmatrix}
_{\text{indirect}}
\]

The left hand side of Eq. 13 represents the orientation \( R \) and the position \( P \) of the instrument while the surgeon has a direct sight, the right hand side represents the orientation and position of the instrument while the surgeon has an indirect sight during MIS. If it is supposed that the
visual reference frame is aligned with the monitor reference frame (monitor is right in front of the surgeon at eye-level) then:

\[ \mathbf{R}_{mon}^{vis} = \mathbf{I} \]

And thus:

\[
\begin{bmatrix}
\mathbf{R}_{vis}^{instr} & \mathbf{p}_{vis} \\
0 & 1
\end{bmatrix}
\begin{bmatrix}
\mathbf{R}_{end}^{instr} \\
\mathbf{p}_{end}
\end{bmatrix}
= \begin{bmatrix}
\mathbf{R}_{end}^{instr} \mathbf{R}_{mon}^{vis} \\
0 & 1
\end{bmatrix}
\begin{bmatrix}
\mathbf{R}_{end}^{instr} \mathbf{p}_{vis} + \mathbf{R}_{end}^{instr} \mathbf{p}_{mon} + \mathbf{p}_{end}
\end{bmatrix}
\]

This equation can be separated into two equations, one for orientation of the instrument and one for the position of the instrument:

\[
\begin{align}
\mathbf{R}_{vis}^{instr} |_{\text{direct}} &= \{ \mathbf{R}_{end}^{instr} \mathbf{R}_{mon}^{end} \} |_{\text{indirect}} \\
\mathbf{p}_{vis} |_{\text{direct}} &= \{ \mathbf{R}_{end}^{instr} \mathbf{R}_{mon}^{vis} + \mathbf{R}_{end}^{instr} \mathbf{p}_{mon} + \mathbf{p}_{end} \} |_{\text{indirect}}
\end{align}
\]

Usually the rotation matrix \( \mathbf{R}_{mon}^{end} \) is unity during MIS so that the image on the monitor is upright, however, from Eq. 16a it can be seen that instrument orientation would correspond if:

\[
\mathbf{R}_{mon}^{end} = (\mathbf{R}_{end}^{instr})^{-1} \{ \mathbf{R}_{vis}^{instr} \} |_{\text{direct}}
\]

\[
\Rightarrow \mathbf{R}_{mon}^{end} = \mathbf{R}_{instr}^{end} \{ \mathbf{R}_{vis}^{instr} \} |_{\text{direct}}
\]

This means that choosing \( \mathbf{R}_{mon}^{end} \) such that Eq. 17 is met will restore the orientation of the instrument on the monitor as if the surgeon was directly looking at the instrument. Unfortunately \( \mathbf{R}_{mon}^{end} \) can not be chosen freely since the endoscopic camera and the monitor are only 2 dimensional and \( \mathbf{R}_{mon}^{end} \) is 3 dimensional. However, rotation of the endoscopic camera can to a great extend restore the orientation of the instrument on the monitor such that left/right and up/down directions correspond again.

**Experimental evaluation of camera-rotation solution**

In the previous section it was derived that rotation of the endoscopic camera (expressed by the rotation matrix \( \mathbf{R}_{mon}^{end} \)) such that instrument orientation corresponds again can improve eye-hand coordination. To evaluate this theoretical solution an experiment was conducted [Wentink]. The experiment consisted of the positioning of a standard surgical instrument along a predefined trajectory in space while having an indirect sight on the instrument via an endoscope and a monitor. Average task time to complete a trajectory was measured. To simulate the hampered eye-hand coordination during MIS, the endoscope was positioned such that a misorientation existed between the real instrument and the displayed instrument, and thus:

\[
\mathbf{T}_{vis}^{instr} |_{\text{direct}} \neq \mathbf{T}_{end}^{instr} \mathbf{T}_{mon}^{end} \mathbf{T}_{vis}^{end} |_{\text{indirect}}
\]

Subjects performed the positioning task during two conditions: \textit{upright camera condition} and \textit{rotated camera condition}. In the rotated camera condition the camera was rotated such that Eq. 17 was approximated:
If the camera is rotated according to Eq. 19, then the misorientation between the real instrument and the displayed instrument is strongly reduced, yielding:

\[
\mathbf{R}_{\text{mon}}^{\text{end}} \approx \mathbf{R}_{\text{instr}}^{\text{end}} \mathbf{R}_{\text{vis}}^{\text{instr}} \mathbf{R}_{\text{direct}}^{\text{end}},
\]

During the experiment subjects looked at a monitor which was located at eye-level right in front of them. The 2 conditions were repeated 3 times to assess the learning effect [Lorenzen, 1993]. At the end of an experiment the subjects were asked to express the experienced mental effort during the two conditions. The Rating Scale Mental Effort (RSME) developed by Zijlstra, 1993 was used to rate mental effort.

The results of the experiment are shown in Figure 5. Rotating the endoscopic camera such that the orientation of the displayed and the real instrument correspond again (Eq. 19 is met) significantly improves eye-hand coordination. Both the average task times and the experienced mental effort are reduced in the rotated camera condition.

![Figure 5: Results of camera-rotation experiment. The left figure shows the average task times (n=20) for the upright and for the rotated camera condition during 3 trials. The right figure shows the average mental effort which was assessed with the Rating Scale Mental Effort developed by Zijlstra, 1993.]

**Conclusions**

In this paper a system theoretical model was proposed to describe eye-hand coordination as a guidance & control problem. It was found that the essence of eye-hand coordination is the transformation matrix \(\mathbf{T}_{\text{vis}}^{\text{prop}}\) which represents the transformation of the visual reference frame to the proprioceptive reference frame. Coordinated hand or instrument movements depend on a correct estimate of \(\mathbf{T}_{\text{vis}}^{\text{prop}}\) in the Central Nervous System. During Minimally Invasive Surgery eye-hand coordination is disturbed due to the indirect sight (via endoscope and monitor) on the instruments. Adapting the model to MIS showed that eye-hand coordination problems during MIS are, in theory, caused by a very difficult to learn (identify) transformation matrix \(\mathbf{T}_{\text{vis}}^{\text{prop}}\). During MIS this transformation matrix consists of the transformation from instrument reference frame to visual reference frame and all the intermediate transformations caused by the endoscope and the monitor.

The theoretical approach of the disturbed eye-hand coordination problem during MIS eventually lead to some practical solutions. One of those solutions involved the rotation of the endoscopic camera.
camera until the orientation of the displayed instrument and the real instrument correspond again. This solution was evaluated in an experiment. It was concluded that endoscopic camera-rotation provides a simple solution to overcome the negative effects of misorientation and to improve eye-hand coordination.

In general this paper proves that it is very useful to approach eye-hand coordination from a system theoretical point of view as a guidance & control problem. The mechanisms which determine good eye-hand coordination can be identified and practical solutions to improve eye-hand coordination are provided.

References


Wentink, M., Endoscopic Camera Rotation; A Conceptual Solution to Improve Eye-hand Coordination in Minimally Invasive Surgery, Minimally Invasive Therapy and Interventional Techniques, in press.