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# MODELS OF REMOTE MANIPULATION IN SPACE

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Astronauts operating in space can hardly be called autonomous. Their progress is constantly being monitored and supported by the ground team. The same procedures will apply to robotic systems in space – no matter how intelligent. This is also true of other important manipulation tasks. For example, a surgeon must perform an operation within a system of supervision and documented procedures which ensure quality care and accountability. What these two domains have in common is a high value environment in which a highly specialized manipulation is performed a small number of times (in contrast to factory automation). Thus robots involved in high value manipulation must be effectively coupled to a human operator either at the work-site or remotely connected via communication links.

Hundreds of hours of man in the loop experiments have been performed to quantify the performance of telemanipulation systems with different levels of capability.

In order to make use of experimental performance evaluation data, models must be developed. Powerful models of remote manipulation by humans can be used to predict manipulation performance in several ways. First, they will allow prediction of performance in future systems based on today's laboratory systems. In this paradigm, the models are developed from experimental data, and then used to predict performance in slightly different situations. Second, accurate telemanipulation models will allow design of manipulation systems which extend manipulation capability beyond its current bounds.

The barriers which are currently being extended by state of the art remote manipulation systems include distance and scale. Distance barriers are most relevant to space telemanipulation although the large manipulators made feasible by the lack of gravity involve scale factors of about 10. Micro-teleoperators are now being developed which couple the operator to micro-worlds. For example, a force reflection system has recently been developed by IBM which couples the operator to the tip of a scanning tunneling microscope: a scale factor of about $10^{-7}$!

The famous time delay problem inherent in overcoming the distance barrier is yielding to new methods in which control is shared between the manipulator and the human operator in ways which allow energetic interaction between manipulator and environment.

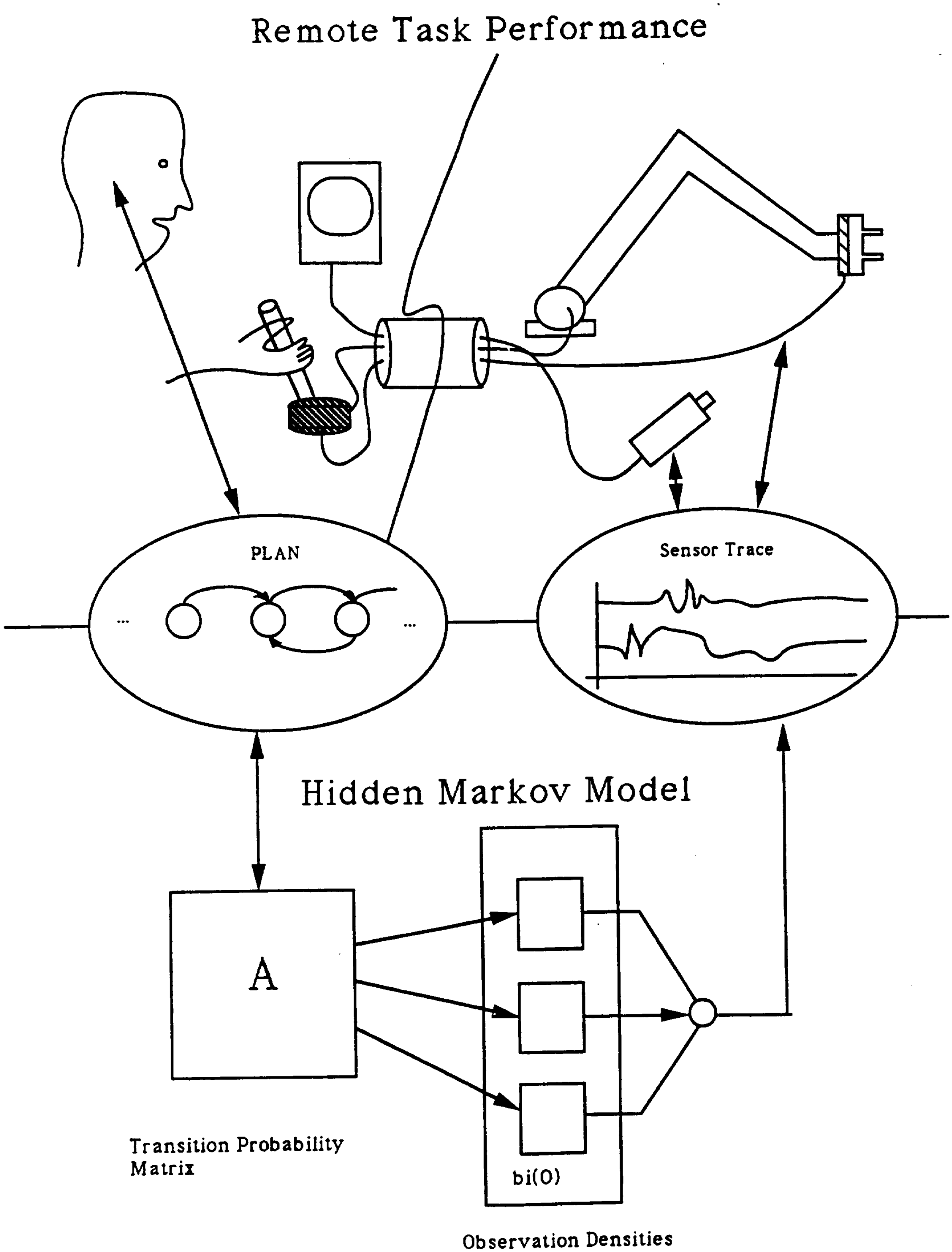
Models developed by several laboratories to explain the dynamics of kinesthetic force reflection will be briefly reviewed and applied to the experimental data. Two-port network models have been successful at improving the understanding and performance evaluation of teleoperators with kinesthetic force feedback in which the human operator, master manipulator, slave manipulator, and environment are coupled together through servo control loops. Such systems can create a sense that the operator directly manipulates the environment.

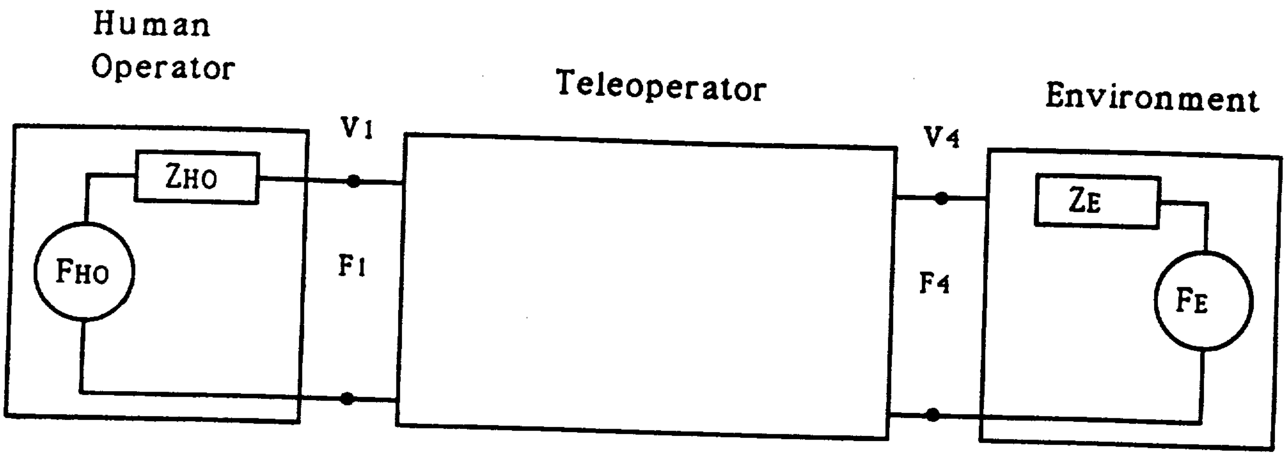
A relatively new model of task performance based on Hidden Markov Models, is able to analyze progression of multi-stage compound tasks. The HMM has several properties that make it attractive for use as a near-real-time execution monitor and post hoc "explainer" in practical applications. Among them are:

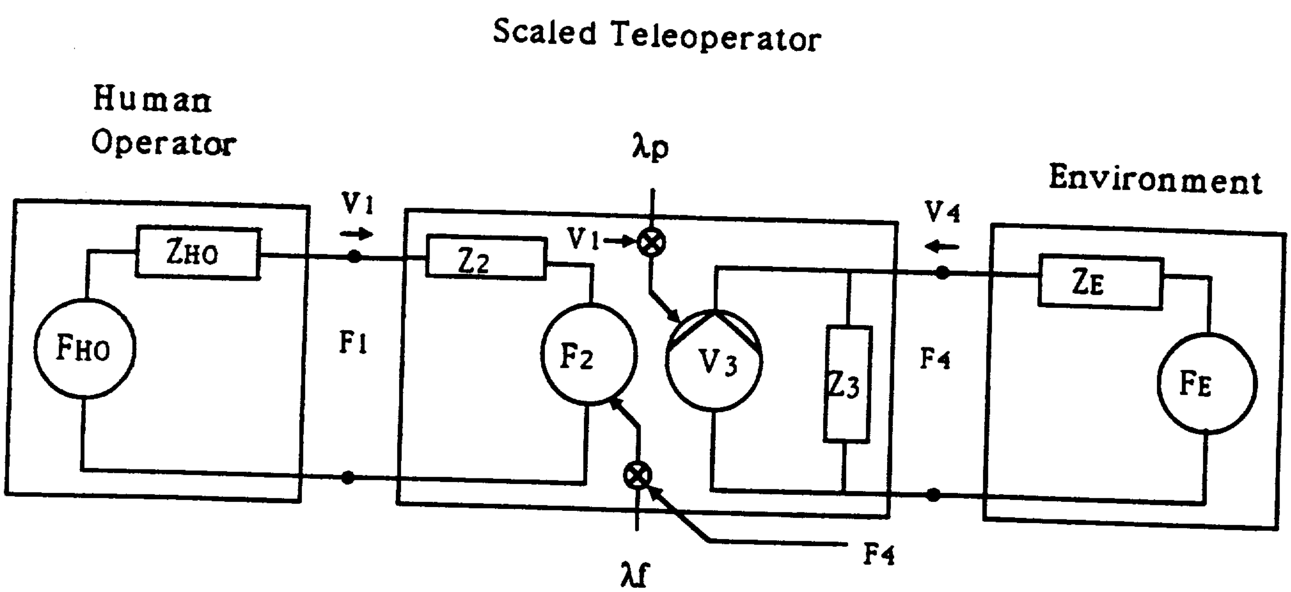
- Explicit Representation of Uncertainty

- Support for "knowledge based" operation (the HMM can be constructed heuristically by an expert).

- Closed form, thoroughly developed, efficient algorithms for state estimation (Viterbi) and model identification (Baum-Welch).


Remote Task Performance
PLAN
Sensor Trace
Hidden Markov Model
A
Transition Probability
Matrix
bi(O)
Observation Densities


Human
Operator
Teleoperator
Environment
V1
V4
ZHO
ZE
FHO
F1
F4
FE


Scaled Teleoperator
Human
Operator
λp
Environment
V1
V4
ZHO
Z2
V1
ZE
FHO
F1
F2
V3
Z3
F4
FE
F4
λf